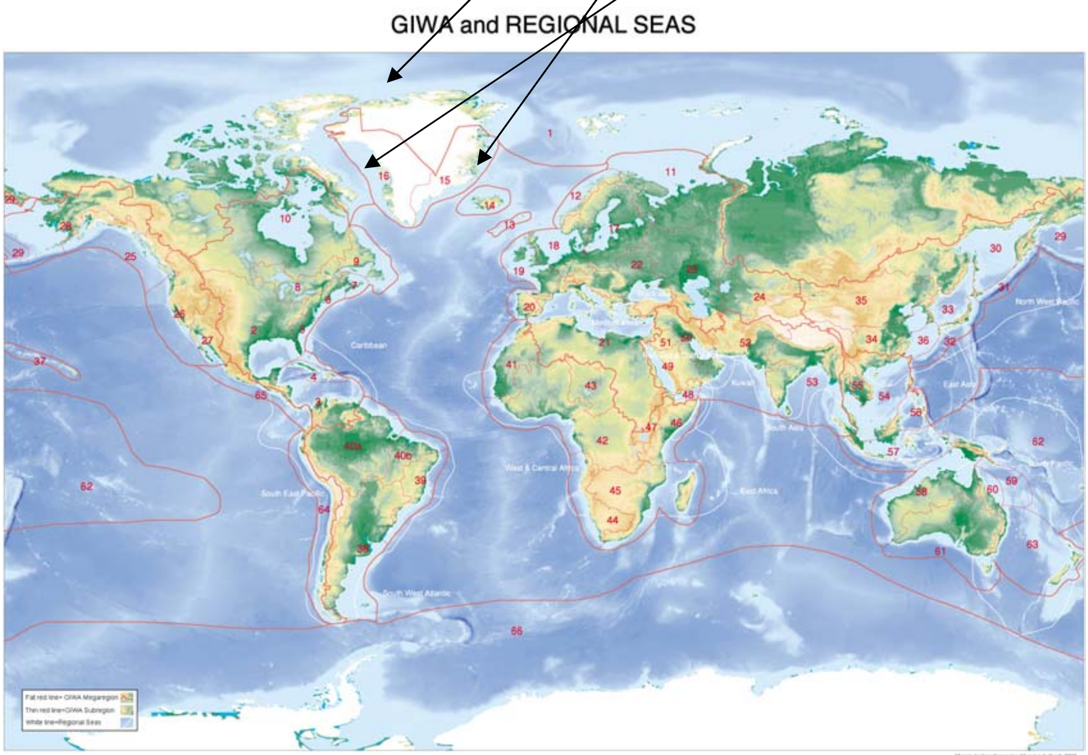
Global International Water Assessment (GIWA)

Greenland - GIWA regions 1, 15, and 16



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National Environmental Research Institute, Denmark,
Greenland Institute of Natural Resources,
UCC-Water

Foreword

Globally, people are becoming increasingly aware of the degradation of the world's water bodies. The need for a holistic assessment of transboundary waters in order to respond to growing public concern and provide advice to governments and decision makers regarding management of aquatic resources has been recognised by several international bodies focusing on global environment. To compile a global overview, the Global International Water Assessment (GIWA) has been implemented by the United Nations Environment Programme (UNEP) in conjunction with the University of Kalmar, Sweden (www.giwa.net).

The importance of the GIWA has been underpinned by the UN Millennium Development Goals adopted by the UN General Assembly in 2000 and the Declaration from the World Summit on Sustainable Development in 2002. The development goals aimed to halve the proportion of people without access to safe drinking water and basic sanitation by the year 2015. WSSD also calls for integrated management of land, water and living resources and, by 2010 the Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystems should be implemented by all countries that are party to the declaration.

This report presents the results of GIWA assessments of the three Greenlandic GIWA regions – Arctic Ocean (1), East Greenland Shelf (15), and West Greenland Shelf (16). The report is the Greenland contribution to GIWA and it is funded by the Danish Environmental Protection Agency (the DANCEA programme). The report has been carried out in collaboration between National Environmental Research Institute (contractor), Greenland Institute of Natural Resources, and UCC-Water.

The report is based on the GIWA Methodology: "STAGE 1: Scaling and Scoping" and "Causal chain analyses" (see www.giwa.net).

Two task team meetings were held in 2003:
1) August 15, at the National Environmental Research Institute in Roskilde, Denmark, and
2) September 3, at the Greenland Institute of Natural Resources in Nuuk, Greenland.

A number of selected experts were participating in these task team meetings. Other selected experts were unable to attend to the meetings. The experts consulted for inputs and reviews of this report are presented in Annex 1.

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Chapter 1: Setting and context

1. Scaling of the sub-regions

The marine waters of Greenland holds by far most of the international aspects in GIWA, whereas land and river issues are of minor or no importance This section describes the boundaries and the main physical and socio-economic characteristics of the region in order to define the area considered in the regional GIWA assessment and to provide sufficient background information to establish the context within which the assessment was conducted. Greenland holds three GIWA sub-regions: Arctic (1), East Greenland Shelf (15), and West Greenland Shelf (16). It was agreed among task team experts to assess Greenland waters in these three predefined sub-regions in order to maintain the comparability with the other UNEP/GIWA sub-regions and to use the GIWA methods. However, there are major differences between ecosystems from south to north within sub-regions 15 and 16 due to differences in physical characteristics, species compositions, and community structures on both the East and West Greenland Shelf (for more details, see section).

1.1. Physical characteristics of Greenland (regions 1, 15, 16)

1.1.1. Geography (location, geology, climate)

Geographically, Greenland is part of the North American continent, geopolitically, a part of Europe. Greenland is the biggest island in the world. It stretches from Nunap Isua (Kap Farvel) in the south at 59°46’ N lat to Odaap Qeqertaa (Odak Island) at 83°40’ N lat (Fig. 1). Nordpynten lies only 700 km from the North Pole, and Kap Farvel, 2,600 km further south, is at the same latitude as Oslo in southern Norway (180 km south of Anchorage, Alaska, USA). The ice-free parts alone have a topography dominated by alpine areas and cover an area of 2,175,600 km^2.

85% of Greenland is covered by a continuous, slightly convex ice cap, which is the world’s second-largest ice sheet. In a borehole drilled in the central part of the ice cap, the drill reached the bedrock in a depth of 3,030 m. The remaining 15% of the island is a narrow stretch of land between the ice cap and the sea, where flora and fauna exists and-the people live – mainly in the coastal areas, with access to open water. The coast of Greenland, which is about 40,000 km long, is mainly rocky and dominated by archipelagos and fjords.

The coast around Greenland is dominated by bedrock shorelines with many skerries and several archipelagos. Very large differences in depths can be found within a short distance in the coastal zone. Some of the world’s largest fjord complexes are found in East Greenland, e.g. Kejser Franz Josephs Fjord and Scoresby Sund, leading out north of the Denmark Strait. In several places the icecap reaches the coast as glaciers at the heads of fjords; so called icefjords. Deep fjords often continue as deep channels outside the coastal line, dividing the offshore banks.

Greenland is located in the Arctic. That means that the average temperature in July does not exceed 10°C, that there is permafrost in most regions, so only the top layers of soil thaw in the summer, and there are no forests. In southwest, however, there is generally no permafrost and at a few locations close to the inland ice the average temperature in July may exceed 10°C. The country can be divided from south to north into sub-arctic, low-Arctic and high-Arctic climate zones. The mean summer temperatures on both the west and the east coast differ by only a few degrees from south to north, despite a distance of more than 2,600 km. The reason for this is the vast iceshield on the one hand, and the summer midnight sun in north Greenland on the other. Conversely, winter darkness and the absence of warm sea currents from North and East Greenland mean that the temperature during the winter period differs considerably from north to south, average temperatures in February 1961-1990: -30.9°C in the north and -3.9°C in the south (see www.dmi.dk).

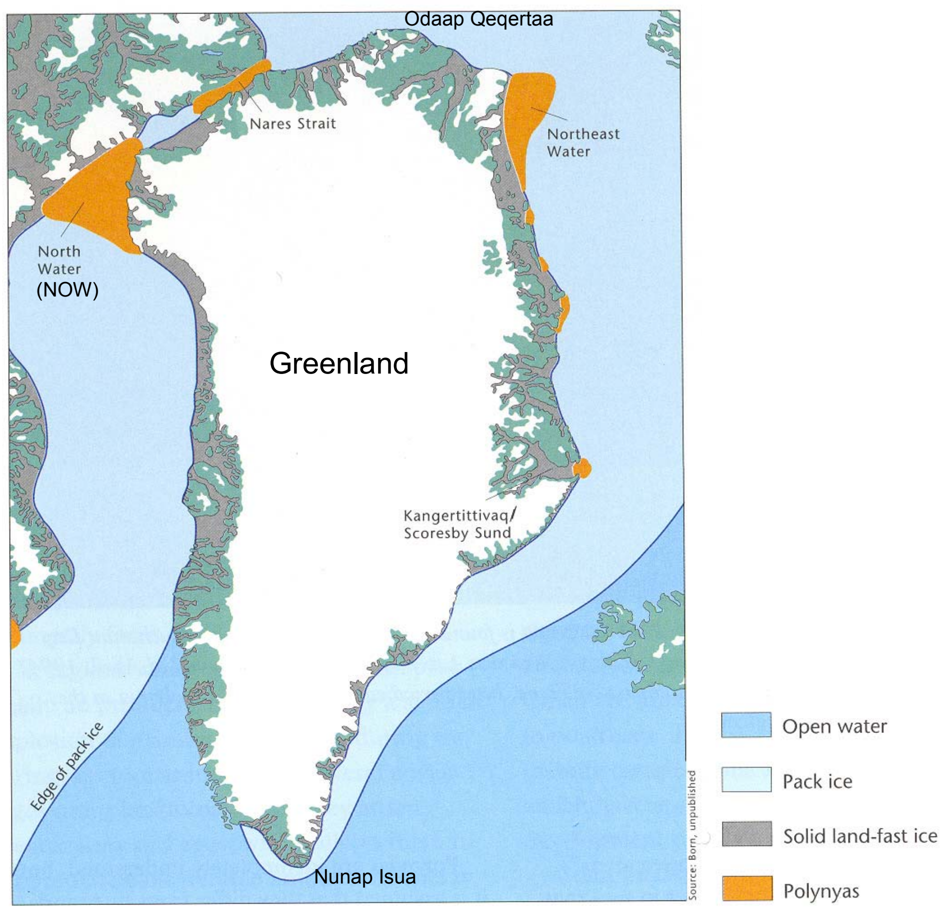

Figure 1 Greenland map showing a typical situation during the winter. The locations of the larger polynyas around Greenland are shown. From Born and Böcher (2001).

The highest temperature officially recorded in Greenland since 1958 is 25.5ºC. It was recorded near the "ice cap" in Kangerlussuaq (West Greenland) in July 1990. In Greenland, frost can occur in principle in all the months of the year except deep inside the large fjords in southern and western Greenland during the summer months. The "frostfree" period in southern Greenland varies from 60 to 115 days per year.

The coldest place in Greenland is naturally on the ice cap, where the temperature can fall to below -70ºC. Temperatures in Greenland have shown a slightly increasing trend for the last 125 years, although, on a shorter time scale, temperatures have generally fallen since the 1940s (Anon., 2003a, Fig. 2.10). This has been most marked on the west coast, where a temperature rise trend has only been seen over the last few years. On the east coast, however, there has been an increasing trend since the 1970s.

Recorded precipitation in Greenland decreases with rising latitude and from the coast to the inland area. In the south and particularly in the south-eastern region, precipitation is significant with average annual precipitation ranging from 800 to 2,500 mm along the coasts. Further inland, towards the ice cap, considerably less precipitation is recorded.

In the northern regions of Greenland there is very little precipitation, from around 250 mm down to 125 mm per year. In the northeasternmost coastal areas there are "arctic deserts", i.e. areas that are almost free of snow in winter, and where evaporation in summertime can exceed precipitation.

Not surprisingly, snow is very common in Greenland. In principle, in the coastal region it can snow anytime during the year without snow cover necessarily forming. The winter snow depth is greatest in southern Greenland, averaging from one to more than two metres in all the winter months and sometimes reaching up to six meters.

The prevailing patterns of wind direction, especially in winter, transport air masses from industrialised areas to the Arctic. The cold Arctic climate seems to create a sink for pollutant compounds (certain heavy metals and persistent organic pollutants...see section 2.2), resulting in a so-called bio-accumulation in higher animals (fish, sea birds, marine mammals), causing concern for human health of Greenlanders consuming these animals.

1.1.2. The Greenland ice cap, icebergs, and sea ice

The Greenland ice cap (1.7 million km^2) holds 9 percent of the world's freshwater. The Greenland ice cap produces about 300 km^3 of icebergs a year. About 10 percent of all Greenland's icebergs stem from one particularly active glacier near the town Ilulissat ("Icebergs" in Greenlandic) in Disko Bay, This glacier (Sermeq Kujalleq) – is the most prolific glacier in the Northern Hemisphere and produces 22 million tons of ice each day (Chisholm and Parfit, 2002).

The extensive sea ice is one of the most characteristic and most important features of the Arctic Ocean, North Greenland and adjacent waters. Sea ice plays a decisive role for marine productivity and life in Arctic Greenland (e.g., Rysgaard *et al*., 2003; Born *et al*., 2003; Wiig *et al*., 2003; Heide-Jørgensen and Laidre, 2004). In the white stretch of frozen Arctic sea, there exist many winter refugia or "microhabitats" for air-breathing marine animals. Several species seek access to open water leads and productive foraging opportunities for many months of the year. The refugia range widely in size, from a few hundred meters to many kilometres of vast open water. They remain ice-free during even the coldest period of winter and are generally surrounded by solid sea ice. Often these areas are annual recurrent 'polynyas' (the Russian word for 'open water area surrounded by ice'), variable shore leads and cracks, or tidal- and/or wind-driven openings in the consolidated pack ice. What defines these microhabitats is that they occur predictably in the same locations year after year, independent of how they are generated and maintained. This geographical and temporal predictability permits numerous Arctic sea birds and marine mammals to utilize open water during winter, when survival in the Arctic sea ice is most critical. Many of these open water habitats demonstrate conspicuous levels of production, generally due to large-scale upwelling events along the ice edge driven by the absence of ice providing early availability of light for photosynthesis. This widely attracts sea birds and marine mammals that seek to benefit from zooplankton production and associated fish abundance in these areas (Heide-Jørgensen and Laidre, 2004).

Species that utilize open water winter refugia include Arctic cetaceans, pinnipeds, sea birds and polar bears and their winter behavioural preferences are specific to requirements for survival and reproductive success (Heide-Jørgensen and Laidre, 2004). One of the largest winter refugia is the North Water Polynya (NOW) found during winter in Smith Sound and the northernmost Baffin Bay (Fig. 1). NOW is utilized during winter and spring by approximately 13,000 belugas or white whales (*Delphinapterus leucas*) (who undertake a northbound migration to this locality from Lancaster Sound in the fall), thousands of narwhals (*Monodon monoceros*), and 30 million little auks (*Alle alle*) feeding in the area prior to the breeding season. Alternate and smaller open water localities of great importance are situated over shallow banks, such as Store Hellefiske Bank in West Greenland, containing vast benthic resources utilized by species such as king eiders (*Somateria spectabilis*) and common eiders (*Somateria mollissima*) and walrus (*Odobenus rosmarus*) with limited diving abilities. Hundred of thousands of thick billed murres (*Uria lomvia*) from Canada, Greenland and Svalbard overwinter in smaller regions along the productive coastal open water area in West Greenland.

1.1.3. Oceanography

Comprehensive descriptions of the physical oceanography of the Greenland waters have been given by Buch (1990), Valeur *et al.* (1997), Buch *et al*. (2003), and Rudels *et al*. (2002).

East Greenland

Waters from the Arctic Basin are transported southward through the Fram Strait along the east coast of Greenland to the Greenland Sea (Fig. 2). The East Greenland Current flows over the Greenland shelf. During spring and early summer it carries large amounts of pack ice along with it. The surface layer in the eastern part of the Greenland Sea is dominated by the northward flowing Norwegian Atlantic Current, an extension of the North Atlantic Current.

The Denmark Strait is the passage between Greenland and Iceland. There is a submarine ridge between Greenland and Iceland, the Reykjanes Ridge. The East Greenland Current flows southward along the coast of East Greenland and rounds Cape Farewell. A branch of the North Atlantic Current, known as the Irminger Current, turns westward along the west coast of Iceland. Part of the current turns further towards Greenland, where it flow southward parallel to the East Greenland Current down to Cape Farewell, where it joins the East Greenland Current (Fig. 2), and flows up the west coast, securing largely open water in the harbours of Southwest and West Greenland.

Southwest and West Greenland

The water masses flowing northward along the West Greenland coast originate partly from the cold East Greenland Current, and partly from the warmer Irminger Current. These two water masses mix intensely. The hydrographic conditions along West Greenland depend greatly on the relative strengths of these two currents. The West Greenland Current, which flows over the Greenland shelf, continues northward until it reaches a latitude of about 65-66^{o} N in the Davis Strait. At this point, a part of it turns westward and unites with the south flowing Baffin Current along the Canadian east coast, and a part continues northward in Baffin Bay.

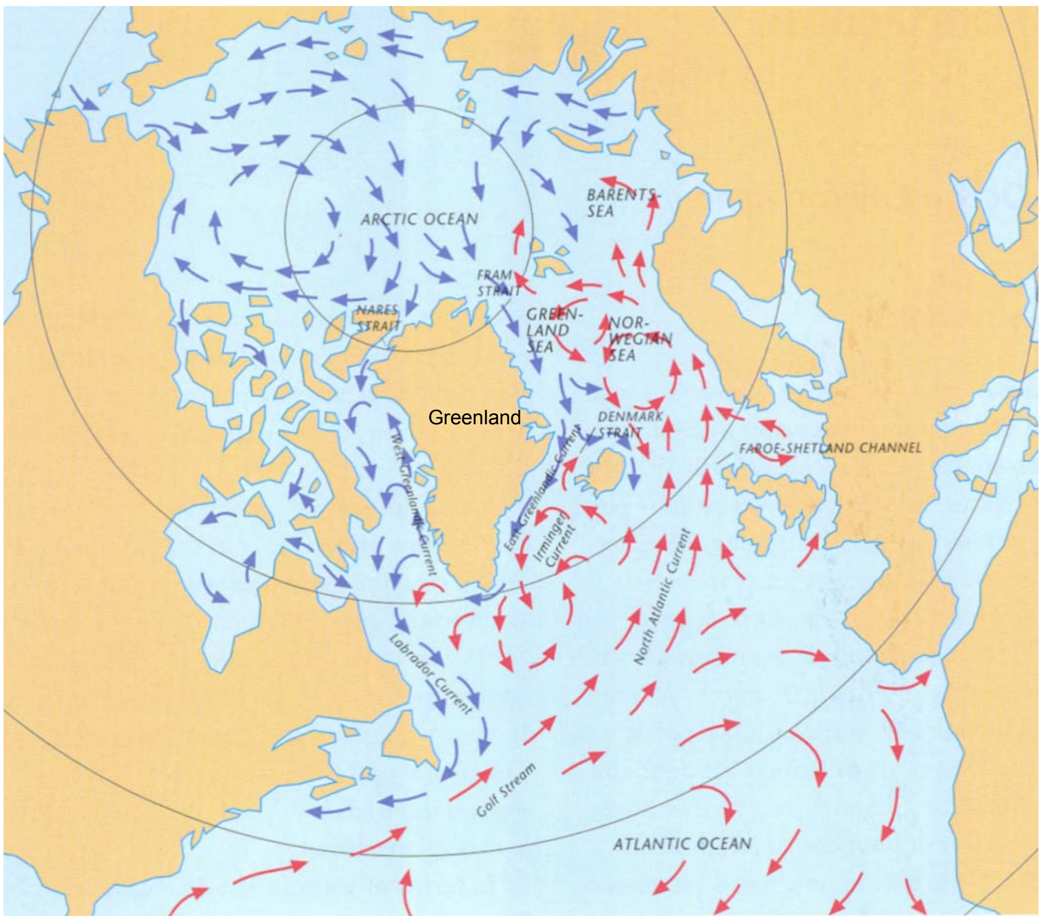

Figure 2 Ocean surface currents. Blue arrows indicate cold currents and red arrows show warm ones. Modified from Born and Böcher (2001) (Source: Dietrick, 1957).

North Greenland

Baffin Bay receives polar water from the Arctic Ocean through the Nares Strait and the Canadian Archipelago. This polar water flows southward along the eastern Canadian coast. Baffin Bay is covered by ice during winter, and in very cold winters, the ice can cover the whole Davis Strait. In summer the ice breaks up and drifts south along Canada's east coast.

Climate-oceanography-sea ice

The oceanographic and sea ice conditions around Greenland are linked to climate variability and the changes in the distributions of atmospheric pressures on the northern hemisphere (e.g., Buch *et al.*, 2001, 2003; Serreze *et al.*, 2000; Johannesen *et al*., 2002; Macdonald *et al.*, 2003). For example the winter (December-March) *North Atlantic Oscillation Index* (NAO-index) tends to be positively correlated with next years winter sea ice concentrations in West Greenland, but negatively correlated with next years sea ice concentrations in Northeast Greenland (Stern and Heide-Jørgensen, 2003). The last decades warming of the northern hemisphere has given reduced summer ice cover and increased open-water periods in East Greenland, however, at the same time regional lower temperatures, increased ice cover, and reduced open-water periods has been observed in West Greenland (e.g. Stern and Heide-Jørgensen, 2003).

1.1.4. Marine ecosystems

Basic information on biological diversity and marine ecosystems in Greenland has been given in Jensen (1999) and Born and Böcher (2001). Specific research and reviews of potential environmental impacts and status of species and their habitats have recently been given in reports and scientific papers e.g. Heide-Jørgensen and Johnsen (1998), Riget *et al*. (2000), Buch *et al*. (2001), Petersen *et al*. (2001), Glahder *et al*. (2003), Mosbech *et al*. (1996, 1998), Mosbech (2002), Pedersen (2003), Møller *et al*. (2003), Born *et al*. (2003), Wiig *et al*. (2003), Buch *et al*. (2003), Rysgaard *et al*. (2003), Hansen *et al*. (2003), Heide-Jørgensen and Laidre, 2004).

Primary production

The annual pelagic primary production in the low arctic south Greenland waters averages 40-80 g C m^{-2} of sea surface. Annual productions as high as 605 g C m^{-2} have been registered. This is more than in most boreal and tropical waters, but still compares poorly with annual productions of 5.5 kg C m^{-2} near Antarctica and over 3.5 kg C m^{-2} off the the Peruvian coast. Sea ice, ocean currents, light, nutrients, temperature, and grassing by herbivores are primary factors determining the distribution of marine productivity and animal life. Areas in which water masses are vertically mixed, with a continuous supply of nutrients to the surface, are especially productive. One example is the front area between polar and Atlantic water masses that predominates off the southeast coast of Greenland. Another is the mixed water mass on the banks off West Greenland, where the surface layers are well supplied with nutrients throughout the summer (Fig. 3).

The annual cycle in primary production in the seas of Greenland is normally initiated in May reaching peak biomasses in June. Large diatoms dominate the spring bloom, but depending on the nutrient availability, the flagellate *Phaeocysis* may also contribute. After the spring bloom where silicate or nitrate is depleted from the surface layer, the phytoplankton biomass is low and dominated by autotrophic flagellates < 10 µm.

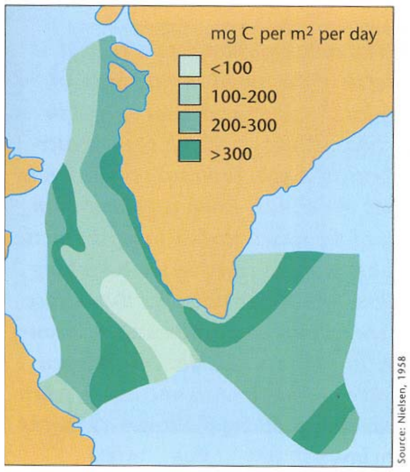

Figure 3 Gross primary production from July to August is greatest along edge of the ice off East Greenland and Labrador and near the coast where bottom water is brought to the surface by upwelling. From Born and Böcher (2001) (Source: Nielsen, 1958).

Obviously there are significant regional differences in the timing and composition of the spring bloom within the northern North Atlantic. While the surface community in the open water is nutrient depleted in the late summer, the continuous supply of nutrients from the melt water at the marginal ice zone can support a high phytoplankton biomass. Thus blooms can be observed at the ice edges throughout the season while it is more episodic in the open water.

To understand the carbon drawdown, it is essential to have a good description of the structure and succession of the zooplankton of the area. The zooplankton influences the carbon dynamics in several ways; by vertical migration, through grazing activity and by acting as accelerators of sedimentation of organic matter through production of faecal material. During the last decade, the views on high latitude pelagic food web structure have changed.

Pelagic food web

The present knowledge of pelagic food chain structure in high latitude ecosystems is primarily based on sampling with coarse nets (> 200 μm) ignoring the smaller components of the food web. However, use of nets with smaller mesh size has documented that the smaller copepod species can contribute significantly to standing stock of the grazer community, especially after the oldest *Calanus* stages have left the surface layer. During the recent cruises in connection to the Danish Global Change Program in the Greenland Sea, a pronounced shift in the copepod community was observed from June to August; in June *Calanus* dominated while the small copepod species and developmental stages of *Calanus* took over in August. It is important to keep in mind that the *Calanus* species have a 2-4 year life cycle while the smaller species likely go through 2-3 generations per year. So the turnover of the copepod community and grazing rates in August is much higher than in June.

Knowledge of the role of the microbial food web in the Arctic has been limited because the microbial loop in cold water ecosystems has been considered less important than at lower latitudes. However, recent comprehensive investigations in Disko Bay, West Greenland, have documented that bacterioplankton and unicellular zooplankton also play a prominent role in the food web of Arctic ecosystems (Hansen *et al.*, 2003).

Young Sund
Since 1994 there has been an extensive research activity in the high Arctic fjord Young Sund (74°N) on the northeast coast of Greenland (Rysgaard *et al*., 2003). In the Young Sund estuary, sea ice algae, primarily diatoms, were heterogeneously distributed in the sea ice both vertically and horizontally. Annual ice algal production at the sea ice-water interface in Young Sund may be highly variable and regulated by the thickness of snow cover. Primary production was <0.01 g C m^{-2} during 1998-1999. Compared to other coastal fast ice areas in the literature this rate seems low but comparable to measurements further out in the Greenland Sea. The low biomass and productivity in Young Sund was caused by a combination of poor light conditions due to snow cover and freshwater drainage from melt ponds and river discharge removing and/or inhibiting the algae at the sea ice-water interface through physical disturbance and exposure to freshwater. Thus, seen on an annual scale, the primary production of sea ice algae in Young Sund was <1% of the pelagic primary production.

In Young Sund the phytoplankton community was dominated by diatoms in the surface samples as well as in the subsurface bloom succeeding the spring bloom. Pelagic primary production was limited by light during sea ice cover. After break-up of the sea ice, silicate initially limited primary production in the surface water due to a well established pycnocline, and maximum photosynthesis occurred in a subsurface layer at 15-20 m depth. In August, production was displaced to deeper water layers presumably due to nitrogen limitation. The carbon budget describing the fate of the annual pelagic primary production revealed that the pelagic production was tightly coupled to the grazer community since total consumption by the grazer community. The classical food web dominated this northeastern Greenlandic fjord and it was estimated that copepods account for >80% of the grazing pressure upon phytoplankton (Rysgaard *et al*., 1999). Based on this study and other values of annual pelagic primary production and sea ice cover found in the literature, annual pelagic primary production in the Arctic was found to increase with the length of the open water light period (Fig. 4). Rysgaard *et al*. (2003) proposed future increase in the annual pelagic primary production, secondary production, and hence food production for higher trophic level animals in a wide range of Arctic marine areas, as a consequence of reduction and thinning of sea ice cover due to global warming. The reduction in sea ice may be a benefit to some marine mammals e.g. Atlantic walruses (Born *et al*., 2003), but probably not for others e.g. polar bears (*Ursus maritimus*) (Wiig *et al*., 2003).

Due to physical differences and because different species have different ranges of temperature and habitat tolerance there are differences in species composition and community structure of the marine ecosystems from south to north along East and West Greenland. Water temperatures and sea ice distributions play a decisive role in determining the distribution of fish, sea birds and marine mammals. For example the distribution of a fish species is limited not only by the temperatures at which the species can survive, but especially by the narrow temperature interval in which reproduction is successful. Accordingly, the geographical range of Greenlandic fish species is primarily determined by the distribution of cold water of polar origin and warmer water of Atlantic origin.

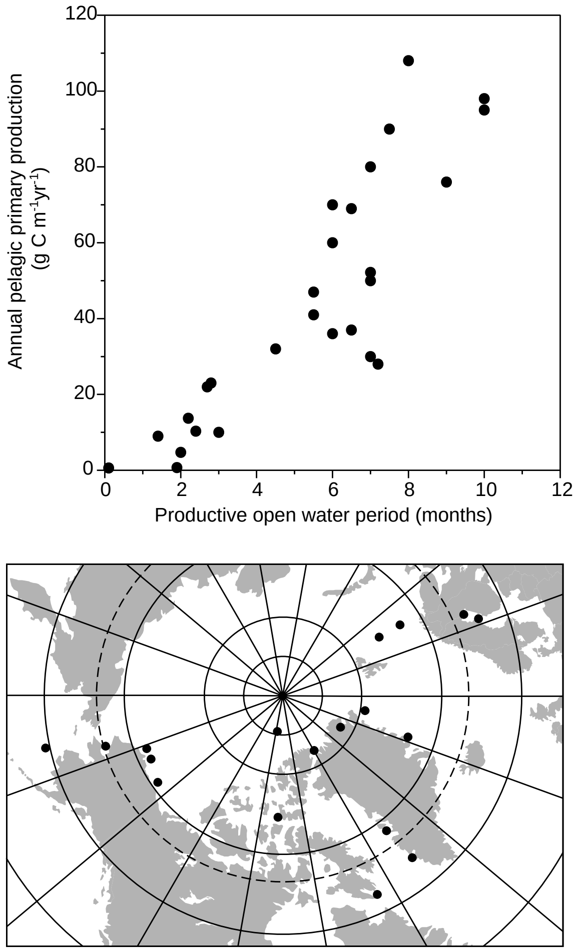

Figure 4 (a) Annual pelagic primary production versus length of productive open water period. (b) Geographical location of investigations. Further details are given by Rysgaard *et al*. (1999).

<u>*Southwest and southeast Greenland*</u>

With respect to commercial fisheries resources, the marine ecosystems of Southwest and Southeast Greenland waters are the most productive in Greenland and the best investigated ones. They are intermediate between the cold polar water masses of the Arctic region and the temperate water masses of the Atlantic Ocean and they are characterized by relatively few dominant species (e.g. Jensen, 1939; Hansen, 1949; Rätz, 1999; Pedersen and Zeller, 2001). Ocean currents that transport water from the polar and temperate regions affect the marine productivity in the Greenland shelf areas, and changes in the North Atlantic circulation system therefore have major impact on the distribution of species and fisheries yield (Pedersen and Rice, 2002; Pedersen *et al*., 2002, 2003; Wieland and Hovgaard, 2002; Buch *et al*., 2003). The relative strengths of the warm vs. cold water currents contribute to the definition of the habitat of the flora and fauna.

<u>*Fish*</u>

Since the beginning of the 20th century, cod (*Gadus morhua*) has been the most important commercial fish species in Greenland waters, with annual catches peaking at levels between 400,000 and 500,000 tonnes in the 1960s (Mattox, 1973; Horsted, 2000). Until the introduction of the 200 mile EEZ in 1977, most of the catch was taken by foreign vessels. During the late 1960s, the annual catches of cod and other commercially important fish species - mainly taken as by-catch in the cod fishery, e.g., redfish (*Sebastes marinus*), Atlantic halibut (*Hippoglossus hippoglossus*) and wolffish (Atlantic wolffish, *Anarhichas lupus*, and spotted wolffish, *A. minor*) declined drastically (Fig. 5).

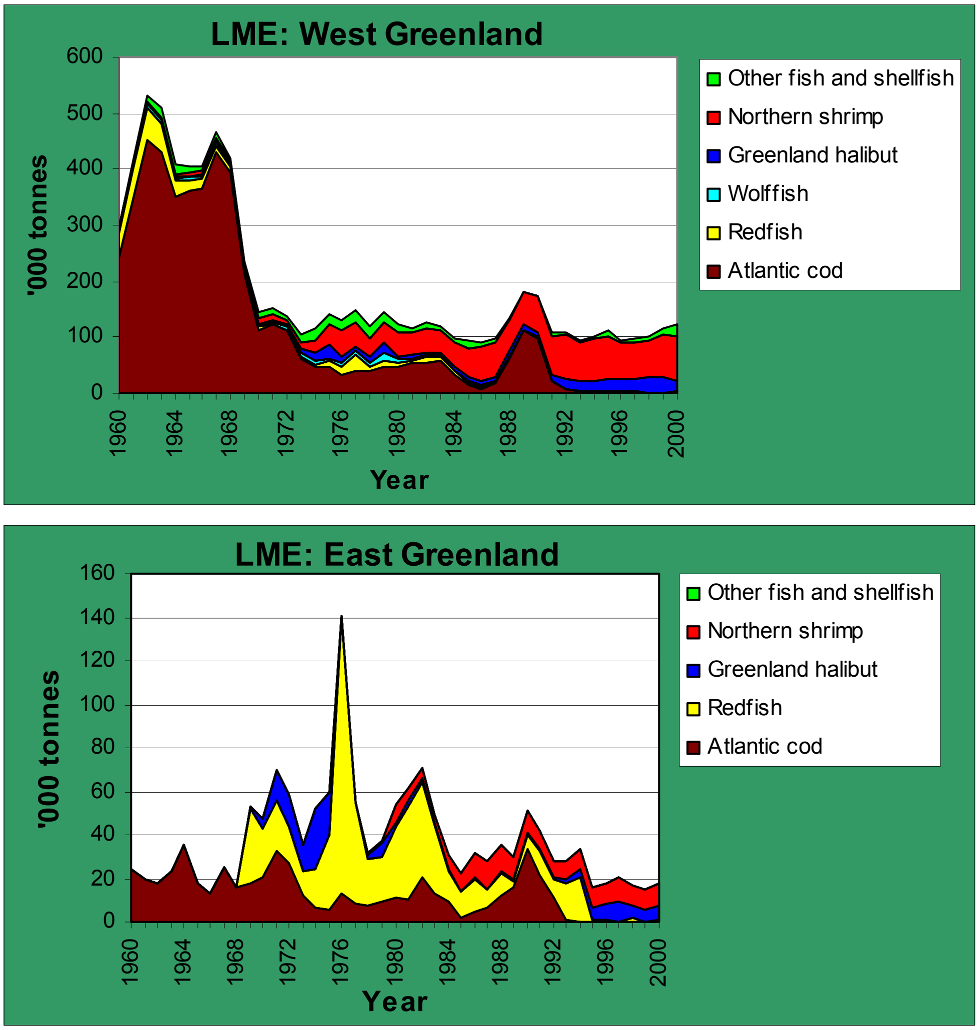

Figure 5 Catches of fish from Sub-region 16, West Greenland Shelf and Sub-region 15, East Greenland (Data from Horsted, 2000; NAFO, 2003; ICES, 2003; and Greenland Institute of Natural Resources. Data for catches of fish in "LME: East Greenland" other than cod is lacking before 1969).

After 1970 the catches of cod and redfish showed fluctuations at much lower levels compared to the 1960s (Fig. 5). Except for a temporary improvement of the cod fishery during 1988-1990, the catches of cod, redfish, Atlantic halibut and wolffish showed decreasing trends towards the present very low levels (Rätz, 1999; Buch *et al*., 2003). During the same period, however, catches (inshore and offshore combined) of two other important species, Greenland halibut (*Reinhardtius hippoglossoides*) and northern shrimp (*Pandalus borealis*) increased and annual catches are presently about 25,000 tons and 100,000 tons, respectively.

Other living resources

In addition to the fisheries yields from mainly the West Greenland, but also the East Greenland large marine ecosystem, one has to add the hunting (and consumption) of more than 100,000 seals, several hundred whales and several hundred-thousand seabirds per year on average (e.g. Mosbeck *et al*., 1998; Greenland Institute of Natural Resources, 2000; Namminersornerullutik Oqartussat, 2002). The seal hunt targets primarily ringed seals (*Phoca hispida*) and harp seals (*Phoca groenlandica*), but also other species including the walrus (*Odobenus rosmarus*). The whale hunt is mainly on fin whales (*Balaenoptera physalus*), minke whale (*B. acutorostrata*), beluga (*Delphinapterus leucas*), narwhal (*Monodon monocerus*) and occasionally others. The seabird hunt is primarily on Brünnich's guillemot / thick-billed murre (*Uria lomvia*), king eider (*Somateria spectabilis*), common eider (*S. mollissima*), little auk (*Alle alle*) and kittiwake (*Rissa tridactyla*). Polar bear (*Ursus maritimus*) is hunted and a total of about 170 animals are killed in Greenland per year with approximately an equal number in West- and East Greenland (Namminersornerullutik Oqartussat, 2002).

1.1.5. Transboundary aspects

The marine animal resources, e.g. fish, sea birds and sea mammals, generally have an extensive distribution area, involving the waters of several nations. This means that fishery, hunting and other influences on one part of a population will eventually affect the rest of it, within as well as outside of Greenland waters. International co-operation on management and protection of marine species and resources is thus imperative if sustainable yields and protections of endangered species are to be attained. Accordingly, Greenland is member of several international organizations that advise a sustainable use of Greenland's marine resources, e.g. North Atlantic Fisheries Organisation (NAFO), International Council for the Explorations of the Sea (ICES), North East Atlantic Fishery Commission (NEAFC), North Atlantic Salmon Conservation Organisation (NASCO), Joint Commission for the Conservation and Management of Narwhal and Beluga (JCNB), North Atlantic Marine Mammal Conservation Organisation (NAMMCO), and International Whaling Commission (IWC).

Greenland's membership of e.g. ICES and IWC is through Denmark and Greenland has an active Greenlandic representation/participation. Greenland is a self-governing part of the Kingdom of Denmark. In 1979 the Home Rule Act transferred the mandate of legislation to the Greenland Parliament in all areas defined to be issues of self-government. Hence, regulations issued in Denmark or international conventions ratified by her are not automatically in force also in Greenland.

In 1991, the eight Arctic countries – Canada, Denmark, Finland, Iceland, Norway, Sweden, Russia, and the United States – initiated the Arctic Environmental Protection Strategy. Under this framework, the countries pledged to work together on issues of common concern. Recognizing the importance of the environment to the indigenous communities of the Arctic, the countries at that time included three indigenous organizations in their cooperative programs. In 1996, the eight Arctic countries created the Arctic Council, incorporating the Arctic Environmental Protection Strategy and expanding it to include sustainable development issues. They have also included three more indigenous organizations for a total of six permanent participants. One of the programs created under the Arctic Environmental Protection Strategy and continued under the Arctic Council is the Arctic Monitoring and Assessment Programme. AMAP was designed to address environmental contaminants and related topics, such as climate change and ozone depletion, including their impacts on human health (AMAP, 2002). In 2000, the Arctic Council approved the Arctic Climate Impact Assessment, overseen by AMAP, its sister working group on Conservation of Arctic Flora and Fauna (CAFF), and the International Arctic Science Committee. According to AMAP (2002), this impact assessment will deliver a report to the Arctic Council in 2004.

Greenland has responded to threats to the freshwater systems and the fauna and flora these habitats support by establishing protected areas and designating important wetland areas under the Convention on Wetlands of International Importance (Ramsar) (Fig. 6; Egevang and Boertmann, 2001).

The objective of the UNESCO Convention concerning World Heritage is to help protecting irreplaceable expressions of former cultures and of natural landscapes of great importance and beauty. The foundations for two international conventions were laid in the mid-1960´s and later, in 1972, merged into one, the UNESCO World Heritage Convention. The five Nordic countries, among others, ratified the convention between 1977 and 1995. As Greenland is not a sovereign state, in these matters Greenlandic interests are upheld through the Danish government.

After a request by the Danish Ministry of the Environment in 1988, the Greenland government has selected natural heritage areas and cultural monuments in Greenland for inclusion in the UNESCO World Heritage List (Mikkelsen and Ingerslev, 2002). This work was properly organised in 1995 when co-operation was established between the Greenland Department of Culture, Education and Ecclesiastical Affairs, the Department of Health, Environment and Research, the Greenland National Museum and Archives, and the Greenland Institute of Natural Resources. The Greenland National Museum selected culturally significant historical objects and the Institute of Natural Resources pointed out areas of special interest for the natural environment. Subsequently, these proposals comprised sites of both natural and cultural history.

The icefjord of Ilulissat/Jakobshavn, West Greenland, which covers an area of 796 square kilometers are being evaluated to become the first UNESCO World Heritage area in the Arctic (Mikkelsen and Ingerslev, 2002). The result of this evaluation will be announced in 2004. The icefjord contains the Jakobshavn Glacier, which is a floating, calving ice cap glacier. The glacier is presently located about 40 km east of the town of Ilulissat. Because of the relatively easy access to the glacier from the settlements in the immediate vicinity, the fjord and glacier are well known. The glacier is particularly famous for its high speed of 1 meter per hour and its production of calving ice which amounts to about 30 cubic kilometers a year. This is more than any other glacier and comprises about 10% of the entire production of calving ice from the Greenland ice cap (Mikkelsen and Ingerslev, 2002).

1.2. Socio-economic conditions

1.2.1. Political structure

Greenland has been a colony of Denmark since 1728, and obtained home rule in 1979, so it is at present a semi-independent province of Denmark. The Home Rule

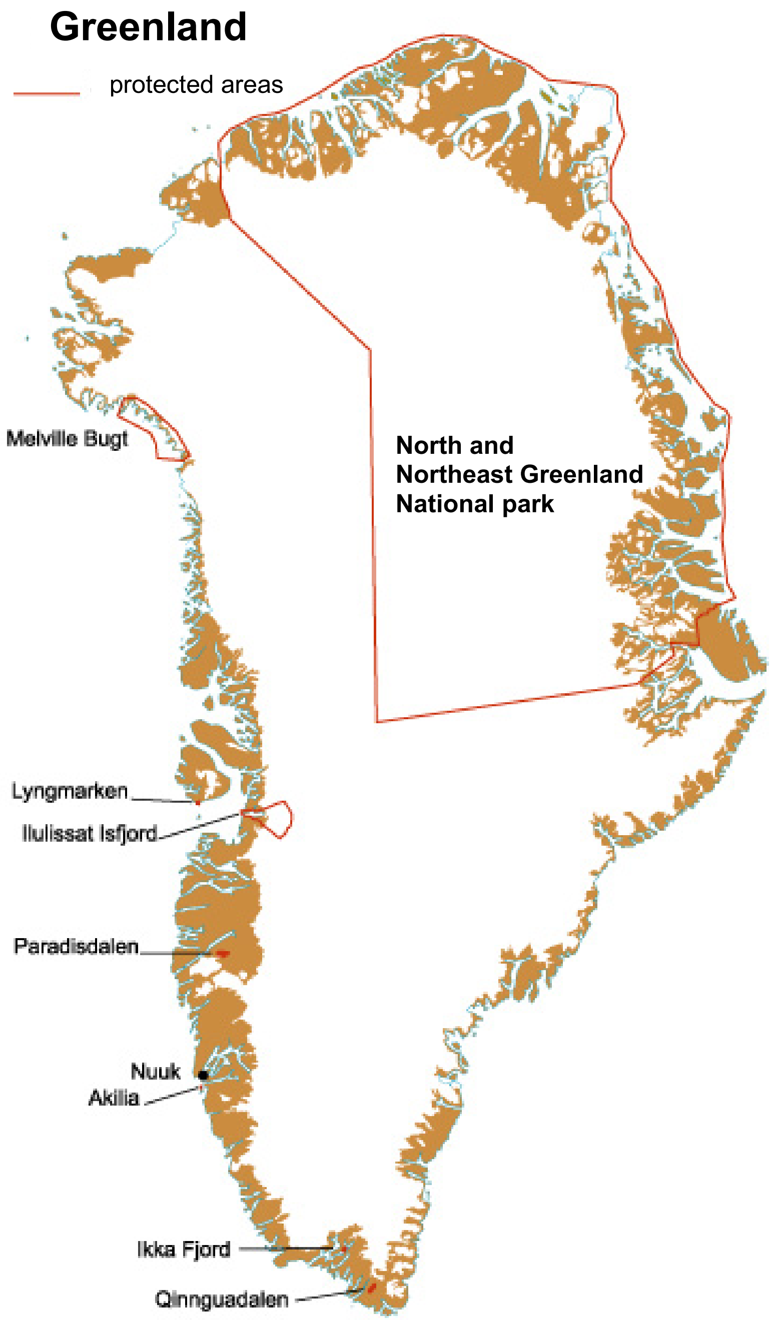

Figure 6 National parks and protected areas indicated by red lines and by their name (Greenland Home Rule, 2004).

Government consists of a directly elected parliament (the Landsting), comprising 31 members. A general election is held every four years. The Landsting elects a government (the Landsstyre), which is responsible for the central administration under the Prime Minister (the Landsstyreformand). The members of the government head the various ministries. As Greenland is part of the Kingdom of Denmark, some fields of responsibility remain under the Danish state, including the Constitution, the right to vote, eligibility for election of justice, the concept of citizenship, inspection and enforcing of jurisdiction in territorial waters, as well as all foreign policy and monetary affairs.

The Home Rule Government is responsible for all other administrative areas, including transport and communication, and the environment and nature. The rights to Mineral and Petroleum are shared between the Danish Government and the Greenland Home Rule. Greenland is not a member of the EU, but has an OCT scheme (Overseas Countries and Territories) that ensures the country open access to the European market for its fish products.

1.2.2. Population

The population of Greenland was 56,542 in 2002 of which ~88% were born in Greenland, which is the official proxy measure for Greenlandic (Inuit) ethnicity (Anon., 2003b). Most of the remainder of the population (~12%) comes from Denmark. The population pyramid for the indigenous population is relatively broad based until the age group 30-34. Around 1970, a very high fertility rates decreased rapidly which, in combination with relatively few women of childbearing age, resulted in small birth cohorts (Fig. 7). After the dramatic decrease, the size of the birth cohorts increased steadily from 1974 to 1995 but is now once more on the decrease (Bjerregaard, 2003).

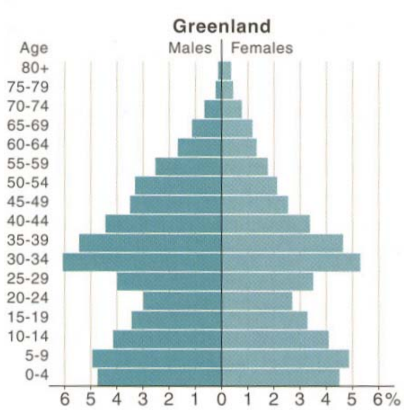

Figure 7 Population pyramid for Greenland, 2001. From AMAP (2003) (Source: Greenland Statistics).

East Greenland is inhabited by only about 3,600 people. West Greenland is inhabited by the majority of the Greenland population, about 53,000 people, and the Greenland fishing industry and all major cities including the Capital Nuuk are situated in West Greenland. In the capital, Nuuk, lives 13,500 people. 80% of the population lives in coastal towns and settlements in Southwest Greenland and the Disko Bay, where also most of the commercial fishing takes place and the fish processing plants are located. Outside this area subsistence hunting and fishing are predominant occupations. The fishery in East Greenland is performed by offshore fishing vessels, both Greenlandic and foreign vessels, whereas the local and coastal fishery is small, but of cultural and sociological importance.

Culture

The Danish/Norwegian colonization of West Greenland started in 1721, and what today is termed the traditional Greenlandic culture is a mixture of Inuit and European culture. The traditional occupation of the Greenlanders until the early 20th century was the hunting of marine mammals (seal, whales, and walrus). During the 20th century hunting was increasingly substituted by fishing, first from small dinghies but later from large sea-going vessels using the most modern equipment. The Greenlandic culture today is still very much centered around traditional Greenlandic food *(kalaalimernit)*, which is understood as the meat and organs of marine mammals and fish often eaten raw, frozen or dried. Seal meat, for instance, is usually ascribed several positive physical as well as cultural qualities, and asking a person whether he or she likes seal meat is equivalent to asking whether he or she considers himself/herself to be a true Greenlander (Bjerregaard, 2003).

Traditional sealing and whaling still plays an important role in the life of people especially in Northwest, North, and East Greenland although it is not the dominant industry in economic terms. Leisure time hunting and fishing is a very common activity.

The consumption of marine mammals, fish and sea birds is high but the young and the population in towns eat considerably less than the elderly and the population in the villages. Seal is the most often consumed traditional food item followed by fish. On average, 20% of the Greenlanders eat seal 4 times a week or more often while 17% eat fish similarly often. Traditional food is valued higher than imported food; the highest preference is given to mattak (whale skin), dried cod, guillemot, and blackberries. Almost all value traditional food as important for health and less than one percent (in 1993-94) restricted their consumption of marine mammals or fish because of fear of contaminants (Bjerregaard, 2003).

Lifestyle

A sedentary lifestyle is becoming increasingly common among the Greenlanders. In the villages, only 7% are self-reported sedentary while this increased to 23% among the well-educated residents of the capital, Nuuk. Overweight is an increasing problem among the Greenlanders; 35% and 33% of men and women, respectively, are overweight (BMI 25.0-29.9) and 16% and 22% are obese (BMI=> 30) (Bjerregaard, 2003).

The consumption of alcohol and tobacco has increased considerably during the last 30-40 years but is now stagnant (Bjerregaard, 2003). The impact of alcohol on social and family life is marked. Among those born after 1960, more than 50% state that they experienced alcohol related problems in their parental home.

According to import statistics, the average consumption of cigarettes increased from 5 cigarettes per day in 1955-59 to 9 in 1990-94. Recent population surveys estimate the proportion of cigarette smokers to be 70-80% among both men and women compared with 40% in Denmark, but the proportions of heavy smokers are similar in the two countries. Young people start smoking very early, often well before the age of 15, and the lowest smoking prevalence is found among the elderly.

1.2.3. Economy

In 1998 gross national income (GNP) was more than 7.5 billion Dkr, corresponding to 134,000 Dkr per capita. (Dkr = Danish Crowns; 1 Euro equals approximately 7.4 Dkr) (Anon., 2003b). Principal income for the Home Rule Government comes from a block grant from the Danish state, which constitutes about 2/3 of the Greenland economy. The remaining 1/3 is overwhelmingly based on fishery and its products. In addition, the Home Rule Government and the municipalities have revenue from personal and corporate taxes, indirect taxes, and licences. In addition, Greenland receives payment from the EU for access by EU fishermen to Greenland's fishing waters.

Exports
In 2001, 87% of Greenland's exports of 2,251 million Dkr consisted of fish products, 60% of which were shrimps (Anon., 2003b). The export value of fish products is heavily dependent on the prices on the world market. Although there was a considerably larger production of shrimps in 2001 than ever, falling prices on the world market considerably reduced the export value.

Imports
Apart from fish and hunting products, only few goods are produced in Greenland. Imports therefore include almost all goods used in households, business and institutions. In 2001 imports amounted to 2,466 million Dkr.

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Industry
Fishing is the main industry, and it is estimated that about 2,500 people are directly employed by it. In addition, around 3,000 people work in the fisheries industry and derivative occupations. Hunting is of direct or indirect significance for about twenty percent of the population, and is the principal occupation Northern and Eastern Greenland. Sheep and reindeer are raised in South Greenland. For many years it was expected that tourism and the extraction of raw materials eventually would become leading industries, supplementing fishing as major sources of income. So far, however, the expectations have not been met.

The fisheries in Greenland are characterized by three main sectors with distinct differences between large scale offshore, intermediate and small scale inshore activities. This is not only due to structural and economic patterns, but also caused by political relations of importance for the development process. The large scale sector is dominated by a capital rationale, with concentration and centralization through large scale projects and economy of scale as the fundamental mechanisms, giving access to resources otherwise inaccessible, and the major contributor to the national economy. The intermediate sector of the regional fisheries is partly based on capital rationality, partly on a life form which has become a backbone of many of the larger settlements, but also present in many smaller settlements. This sector is important for the regional economies. The small scale sector, relying on small boats, dog-sledges and skidoos, is vital for the small settlements, and consequently constituting the backbone of the cultural heritage, and important for the direct and indirect political attempts to maintain reasonable living conditions for the smaller places. At the same time its contribution to the maintenance of the informal and subsistence sector is certainly not negligible (Rasmussen, 1998c; Caulfield, 1997; Marquardt and Caulfield, 1995).

1.2.4. Fishing and hunting

Northern shrimp (*Pandalus borealis*) constitute the most important commercial export. The annual catches of around 100,000 tons contribute more than 1 billion Dkr to the Greenland economy. However, this contribution is depending on e.g. the world marked prize for shrimp products.

Cod (*Gadus morhua*) previously played a central role in the development of the economy, but the cod landings have fallen to <2,000 tons and cod fishing in Greenland today is of very low economic importance compared to former periods.

Greenland halibut (*Reinhardtius hippoglossoides*) on the other hand, has in the last 2 decades become important to the economy of the country. The yearly catch of more than 20,000 tons comes first and foremost from the northwesterly districts.

Redfish, catfish, Atlantic halibut, salmon and char are of minor economical importance, however, important to the local socio-economy in towns of Southwest Greenland.

A number of marine mammals are essential for the survival of the traditional hunting communities. The most important of these are the five species of seal which are found in the waters around Greenland. The most common is the ringed seal, and the Greenlanders still harvest around 80,000 of these every year whereas they also harvest 80,000 of all the other species put together. A number of walruses and whales are also caught (see section 2.4). Considerable sums are involved in the lively trade in meat which is only used locally. The only commercial use of the seals comes from the sale of skins to the Great Greenland tannery in Qaqortoq (Julianehåb). The Home Rule Government provides generous subsidies to the sealers because of the difficulty in selling the skins on the world market. Polar bear hunting and the sale of polar bear skin are socio-economical important locally in West and East Greenland.

The rich bird life around the coasts has also played a role in the life of the Greenlanders. In addition to a number of different types of gulls and ducks, of which the most important is the common eider, uses have also been found for a number of colony birds, not least Brünnich's guillemot, known commonly as the polar guillemot.

The fishing and marine mammal hunting in Greenland is founded on resource assessments and quotas given by international advisory organisations and committees on fishery and marine mammal management (NAFO, ICES, NASCO, NEAFC, JCCM, NAMMCO, and IWC) of which Greenland is a member. The Greenland Institute of Natural Resources is responsible for providing scientific advice on the level of sustainable exploitation of the living resource to the Greenland Government, including long-term protection of the environment and biodiversity. As of today, the scientific advice to the Greenland Government of sustainable use of the renewable resources is entirely based on single-species assessments given for one year. However, for northern shrimp (the most important commercial fishery) an analytical assessment framework using a stochastic version of a surplus-production model that included an explicit term for predation by cod was applied for the first time in 2002.

Today cooperation between Greenland and EU is dominated by fisheries agreements. Within these agreements EU pays Greenland for rights to fish parts of the quotas of the Greenland fish stocks. However, from 2007 Greenland and EU are expected to make a wider partnership agreement.

The Greenland Government regulates the utilization of renewable resources by quotas, license's and technical measures (e.g. mesh sizes or closed seasons) (Namminersornerullutik Oqartussat, 2002; www.nanoq.gl). To enforce the decided regulations and laws on fishing and hunting, Greenland has established the "Greenland Fishing License Control" (GFLK) and "Greenland Hunting Patrol" (Jagtbetjentordningen).

1.2.5. Farming and land use

Geographically, Greenland's agriculture is placed in the south. It consists mainly of sheep farming, and 25,000-30,000 lambs are produced each year. There are also two farms with domesticated reindeer. The number of sheep has remained relatively stable since 1990, whereas the number of domesticated reindeer has more than halved. The area farmed has increased by 85% since 1990 due to cultivation of heath lands for hay cutting.

There is no forestry in Greenland apart from four experimental plantations with conifers, with a total area of 100 ha.

In Greenland there are no roads connecting towns. Therefore all traffic between towns and settlements is either by ship, boat, dog-sledge (seasonally), snowscooter (seasonally) or by fixed-wing aircraft or helicopter. In the towns most goods are transported by car. The main gateways to Greenland are the international airports (former American military bases) in Narsarsuaq (South Greenland) and Kangerlussuaq (West Greenland). From here traffic to all Greenland destinations is being distributed – either by small airplanes or by helicopters. The two towns in East Greenland are accessible by air from Iceland.

Almost all goods transport, both to and within Greenland, is by sea. A small proportion, mainly mail and perishable goods, is transported by air. Only the areas from Paamiut (Frederikshåb) to Sisimiut (Holsteinsborg) on the west coast is open water all year round, and therefore accessible by boat. South of Paamiut (Frederikshåb) drift ice from the east coast can cause trouble for fisheries and transportation in the summer months. North of Sisimiut (Holsteinsborg), ice conditions limit navigation during winter. On the east coast ice may cause troubles year round, as the east coast can only be navigated for a few months in the summer.

1.3. Conclusion

The GIWA sub-regions of Greenland, Arctic (1), East Greenland Shelf (15), and West Greenland Shelf (16), cover huge areas, but they are sparsely populated. The development of modern Greenland has been based on fishing and hunting natural resources. Besides the importance of transfers from Denmark, the society of Greenland, including the local economies, depends on living resources from the sea, and more than 90% and Greenland’s total export value stems from fish products. Likewise, the social and physical health of Greenlanders, notably those living in the more isolated areas, depends to a high degree on the collection and consumption of traditional food.

Chapter 2: Assessment of major concerns

This section presents the results of the task team assessments of the impacts of each of the five predefined GIWA concerns i.e. Freshwater shortage, Pollution, Habitat and community modification, Overexploitation of fishes, birds, marine mammals, and other living resources, Global change, and their constituent issues and the priorities identified during this process. The evaluation of severity of each issue adheres to a set of predefined criteria as provided in the chapter describing the GIWA methodology. In this section, the scoring of GIWA concerns and issues is presented in Table 1, 2 and 3. Detailed scoring information is provided in Annex 2 of this report.

Table 1 Scoring table for Arctic North Greenland (Sub-region 1). 0=no known impact; 1=slight impact; 2=moderate impact; 3=severe impact.

Arctic North Greenland Sub-region 1	**Environmental impacts**	**Economic impacts**	**Health impacts**	**Other community impacts**	**Overall Score**	**Priority**
I Freshwater shortage	0	0	0	0	0	4
Modification of stream flow	0					
Pollution of existing supplies	0					
Changes in the water table	0					
II Pollution	2	0	0	0	2	3
Microbiological	0					
Eutrophication	0					
Chemical	2					
Suspended solids	0					
Solid wastes	0					
Thermal	0					
Radio nuclide	0					
Spills	0					
III Habitat and community modification	0	0	0	0	0	2
Loss of ecosystems	0					
Modification of ecosystems	0					
IV Unsustainable exploitation of fish	0	0	0	0	0	5
Over-exploitation	0					
Excessive by-catch and discards	0					
Destructive fishing practices	0					
Decreased viability of stock through pollution and disease	0					
Impact on biological and genetic diversity	0					
V Global change	2	0	0	0	2	1
Changes hydrological cycle	2					
Sea level change	0					
Increased UV-b radiation as a result of ozone depletion	1					
Changes in ocean CO_2 source/sink function	1					

Table 2 Scoring table for East Greenland (Sub-region 15). 0=no known impact; 1=slight impact; 2=moderate impact; 3=severe impact.

East Greenland Sub-region 15	**Environmental impacts**	**Economic impacts**	**Health impacts**	**Other community impacts**	**Overall Score**	**Priority**
I Freshwater shortage	0	0	0	0	0	5
Modification of stream flow	0					
Pollution of existing supplies	0					
Changes in the water table	0					
II Pollution	3	0	3	3	3	1
Microbiological	0					
Eutrophication	0					
Chemical	3					
Suspended solids	0					
Solid wastes	0					
Thermal	0					
Radio nuclide	0					
Spills	0					
III Habitat and community modification	1	0	1	0	1	3
Loss of ecosystems	0					
Modification of ecosystems	1					
IV Unsustainable exploitation of fish	3	0	2	0	3	2
Over-exploitation	3					
Excessive by-catch and discards	1					
Destructive fishing practices	3					
Decreased viability of stock through pollution and disease	0					
Impact on biological and genetic diversity	0					
V Global change	1	0	0	0	1	4
Changes oceanography	1					
Sea level change	0					
Increased UV-b radiation as a result of ozone depletion	1					
Changes in ocean CO_2 source/sink function	1					

Table 3 Scoring table for West Greenland (Sub-region 16). 0=no known impact; 1=slight impact; 2=moderate impact; 3=severe impact.

West Greenland Sub-region 16	**Environmental impacts**	**Economic impacts**	**Health impacts**	**Other community impacts**	**Overall Score**	**Priority**
I Freshwater shortage	0	+1	0	0	0	5
Modification of stream flow	1					
Pollution of existing supplies	1					
Changes in the water table	0					
II Pollution	2	0	3	0	2	2
Microbiological	0					
Eutrophication	0					
Chemical	2					
Suspended solids	0					
Solid wastes	1					
Thermal	0					
Radio nuclide	0					
Spills	0					
III Habitat and community modification	2	0	0	0	2	3
Loss of ecosystems	0					
Modification of ecosystems	2					
IV Unsustainable exploitation of fish	3	0	0	0	3	1
Over-exploitation	3					
Excessive by-catch and discards	1					
Destructive fishing practices	3					
Decreased viability of stock through pollution and disease	0					
Impact on biological and genetic diversity	0					
V Global change	1	0	0	0	1	4
Changes oceanography	1					
Sea level change	0					
Increased UV-b radiation as a result of ozone depletion	1					
Changes in ocean CO_2 source/sink function	1					

2.1. Major Concern: Freshwater shortage

The Greenland ice cap contains nine percent of the world's fresh water. Greenland's water is renowned as some of the finest in the world. The purity of the water has been measured at various locations in Greenland in order, so to speak, to set the instruments used for measuring pollution at zero (Pedersen, 2002).

Environmental impacts

Modification of stream flow

One river has been regulated due to build a hydropower dam outside of Nuuk, the Capital of Greenland, situated in West Greenland (sub-region 16). However, modification of stream flows in Greenland is generally considered an environmental problem of minor concern. Hydropower was considered as a socio-economic benefit for Greenland as the country has no own oil or gas resources. A few other hydro power plants are planned.

Pollution of existing supplies

Although clean water is plentiful there are special factors in Greenland that have to be taken into account when water is piped into the towns for use by households and the fishery industry (Pedersen, 2002).

In all towns, the water is chlorinated at the waterworks to combat harmful bacteria in the drinking water. When the content of humus and silt is high, so-called trihalomethanes sometimes form in connection with chlorination. Trihalomethanes are suspected of being carcinogenic, so there is every reason to try to prevent them from forming. Therefore, the local authority in Ilulissat (Jabokshavn) adds aluminium sulphate to the water at the same time as it is aerated, whereby the humus and silt are removed before the water is chlorinated (Pedersen, 2002).

Surface water is only chlorinated in towns. In settlements, where the water is not chlorinated, this can mean that food products cannot be directly processed for export. The EU's Drinking Water Directive demands a water quality that is free of micro-organisms, parasites and substances in quantities or concentrations that present a potential risk to health. All new waterworks are designed and constructed to meet the EU's requirements for reasons of public health and the export of Greenlandic food products (Pedersen, 2002).

Changes in the water table

No evidence that use of water from aquifers exceeds natural replenishment.

Socio-economic impact

Economic impact

West Greenland (sub-region 16) a hydro power plant outside the Capital of Greenland, Nuuk, has been positive for the economic development.

Health impact

No known impact.

Other Social and Community impacts

In several settlements the access to a continuous flow of drinking water is limited throughout the year. In some settlements in the north the supply of freshwater during winter is based on the melting of ice, which is expensive and may open up for contamination. In a few settlements in the south the sources of drinking water can become scarce during summer, and can then be limiting for commercial fish processing (Friis and Rasmussen, 1989). In several settlements freshwater is so scarce that supplies are produced from seawater by osmosis.

Conclusion

Freshwater shortage is generally not a problem of major concern for Greenland at present or in the foreseeable future. Greenland holds plenty of unpolluted water in the ice cap and in lakes and rivers. However, the surface of the ice-cap can be contaminated with persistent organic pollutants (see later, Jacobsen *et al*.(2003)).

2.2. Major Concern: Pollution

The experts agreed that pollution and almost exclusively chemical pollution has a moderate to severe impact and it is an issue of major concern for Greenland at present.

A comprehensive assessment of the levels and trends of contaminants in the Greenland marine environment, their effects in the environment, particularly in sea-birds, ringed seals, polar bears and to human health have recently been made in connection with the Arctic Monitoring and Assessment Programme (AMAP) (Riget *et al*. 2003; Deutch and Hansen, 2003; AMAP, 2002, 2003).

In general, people in Greenland are more exposed to contaminants from their diet than people in Europe and North America, who eat processed foods under strict standards. The reason is that marine traditional food items (fish, seabirds, seals and whales) are much more important in the Greenland diet, and at the same time some of these food items have high levels of contaminants, i.e. metals such as mercury and cadmium and organochlorines such as PCBs. Within the Arctic, Greenlanders have the highest concentrations of mercury and PCBs (Hansen, 1998).

Since the Arctic lies far from the industrialized world, one would not expect environmental problems to be serious. However, the presence of chlorinated organic compounds and heavy metals in arctic food chains testifies to the fact that certain pollutants are transported over long distances to the Arctic. Pollutants enter the Greenland marine environment via the atmosphere and ocean currents. The importance of sources and pathways are not fully understood, but in general the anthropogenic contribution to the contaminant levels is expected to be dominated by pollutants originating from sources outside Greenland.

Numerous inorganic and organic pollutants occur in the industrial products of daily use, leading to a current emission into the environment, where they will be transported by the atmosphere and the sea. Studies in the Arctic region have shown that long-range transport of compounds produced and emitted in industrialised countries to the remote regions of the Arctic takes place. Additionally, the use of imported industrial products in the Arctic has also been indicated to lead to a certain emission of pollutants.

Coal burning, waste incineration and industrial processes around the world emit mercury to the atmosphere, where natural processes transport the metal. The Arctic is vulnerable because unique pathways appear to concentrate mercury in forms that are available to the food web. Environmental changes, e.g. increase in the distribution of wetlands due to melting of permafrost may have made these pathways more efficient in recent years (AMAP, 2002). However, the pathways for contaminants between its deposition to surfaces, and its concentration in apex aquatic feeders are very poorly known (AMAP, 2002).

Environmental impacts

Chemical pollution

Heavy metals

Metals are naturally occurring elements. They are found in elemental forms and in a variety of other chemical compounds. Each form or compound has different properties, which affect how the metal is transported, what happens to it in the food web, and how toxic it is. Some metals are vital nutrients in low concentrations.

The metals raising most concern in the Arctic are mercury and cadmium. They have no known biological function but bioaccumulate, can be toxic in small quantities, and are present at high levels for a region remote from most anthropogenic sources.

The rise of the sun after the polar winter is a time of celebration in the Arctic. The lengthening days herald warmer weather and the return of migratory animals. But the recent discovery that the Arctic may be an important global sink for atmospheric mercury casts a shadow over polar sunrise (AMAP, 2002).

Each spring, a substantial amount of airborne mercury is deposited on Arctic snow and ice as a result of reactions spurred by sunlight (AMAP, 2002; Macdonald *et al.*, 2003). Once in the snow, some of the mercury is present in reactive, biologically available forms. As the snow melts, some of the mercury can enter the food web just as the burst of spring productivity begins, a time when life in the region is vulnerable.

In mammals, mercury causes nerve and brain damage, especially in fetuses and the very young (AMAP, 2002). It can also interfere with the production of sperm. In birds, high levels of mercury can cause erratic behaviour, appetite suppression, and weight loss. At lower levels, egg production and viability are reduced, and embryo and chick survival are lower. Outside the Arctic, some seabirds show signs of kidney damage from accumulated mercury. Fish exposed to high mercury levels suffer from damage to their gills and sense of smell, from blindness, and from a reduced ability to absorb nutrients through the intestine. Plants with high concentrations of mercury show reduced growth.

Sonne-Hansen *et al*. (2003) compiled the available knowledge of contaminant effects in the Greenland environment. Although histopathological changes were observed in 10% of the ringed seal kidneys these were not specific enough to be concluded as cadmium induced. No demineralisation in the skeletal system could be linked to cadmium levels and/or nephropathological changes in selected ringed seals from northwest Greenland with high cadmium levels in the kidney. Furthermore the degree of mineralisation of the skeleton was not correlated with gender but was highly significant correlated to age.

The knowledge of heavy metals in the Greenland environment is summarized in Table 4.

Table 4 Heavy metals in the environment in Greenland (Riget *et al*., 2003a,b).

Heavy metals	
Fresh water environment	Mercury (Hg) concentrations in landlocked Arctic char in Greenland are relatively high especially in southwest Greenland. No significant difference was found in Hg concentrations in Arctic char from southwest Greenland between 1994/95 and 1999.
Marine environment	Recently observed cadmium (Cd), mercury (Hg) and selenium (Se) levels in marine biota were generally within the range observed previously in the mid 1980'ies. The recent Cd data confirms the previously observed relatively high level in the marine biota from Qeqertarsuaq (central west Greenland) compared to other Arctic regions. Beside that, no pronounced difference in Cd levels between marine biota from west and east Greenland was observed. Hg levels tended to be higher in east Greenland than in west Greenland for shorthorn sculpin, black guillemot (egg) and ringed seals, whereas polar bears appear to show the opposite pattern. Only few time series of Cd and Hg data covering the recent 20 years are available so no firm conclusions can be made concerning trends. Cd in ringed seals from Avanersuaq and Ittoqqortoormiit tended to have lower levels in 1994 and 1999/2000 than in the mid 1980'ies. In Qeqertarsuaq Cd levels tended to be higher in 1994 than in 1999/2000 in ringed seals, and Hg concentrations in blue mussels and ringed seals tended to have higher levels in 1994 than in 1999. In Avanersuaq, Hg levels in ringed seals showed an increasing trend from the mid 80'ies to mid 90'ies and again to 1999/2000. In Ittoqqortoormiit, no apparent trend in Hg levels was observed in ringed seals and polar bears. Seabirds hunted with lead shot have significantly elevated lead levels in their muscle tissues. This probably constitutes the most important single lead source in Greenland human diet (Johansen *et al*., 2004). Greenland marine sediments are not enriched by arsenic as reported for large areas of the Barents Sea.

Persistent organic pollutants (POPs)

The evidence that persistent organic pollutants affect Arctic wildlife is accumulating (AMAP, 2002). The class of POPs covers a large number of chemicals with some common characteristics that make them potential problems in the environment. By definition, POPs are persistent, which means that they break down slowly in the environment. Persistent chemicals are more likely to be transported over long distances and reach remote regions such as the Arctic. Once in the Arctic, some compounds may last even longer in the cold and dark environment than they would in more temperate climates (e.g. Jacobsen *et al*., 2003).

Many POPs are taken up by organisms, either directly from their surroundings or via food. If the chemicals cannot be broken down or excreted as fast as they are taken up, they will accumulate in the organisms' tissues. Most POPs are poorly soluble in water but readily soluble in fat and therefore become concentrated in the fat of animals. At high enough levels, many POPs can have adverse effects on wildlife and on human health, including effects on reproduction, development, and resistance to disease.

POPs have a range of potential effects on animals. A sensitive target is the immune system, where new information reveals that effects are apparent among some Arctic populations of polar bear, northern fur seals, and glaucous gulls. Current contaminant levels may also pose a threat to reproduction and brain development in wildlife. POPs interacting with hormones, especially during development in the womb or at a very young age, is probably a common link between many effects. The knowledge of POPs in the Greenland environment is summarized in Table 5.

Other contaminants of concern

Up to now the main focus on long range transported POPs has been on strongly hydrophobic organic pollutants such as polychlorinated biphenyls (PCBs) and chlorinated pesticides. Due to the hydrophobic character of the compounds they will primarily be linked to organic matter of similar polarity and thus be likely to concentrate in sediment and/or to accumulate in animal lipids. The compounds have been found to bioaccumulate in animals and the highest levels are found in the top predators of the Arctic. As marine food, including tissues from the top predators, contributes significantly to the diet of many people in the Arctic, humans are exposed to a high intake of organochlorines and metals, which may affect their health.

However, other groups of organic chemicals could also be of concern in the Arctic (Table 6). Brominated and fluorinated compounds are examples. These compounds have many physical and chemical properties in common with their chlorinated counterparts and can therefore be expected to increase in the Arctic environment in the same manner as the chlorinated substances. Some compounds might be more persistent at higher latitudes than further south. This may be a problem if the compounds are toxic at very low concentrations.

Table 5 Persistent organic pollutants (POPs) in the environment in Greenland (Riget *et al*., 2003a,b).

POPs	
Fresh water environment	Organochlorine (CO) levels in landlocked Arctic char were in the same range as found in marine fish species. No consistent geographical pattern of OC concentrations was observed. Concentrations of ∑DDT, ∑HCH and ∑CHL were lower in a southwest Greenland Arctic char population in 1999 than in 1994. No significant changes were found of ∑PCB-10 and HCB concentrations between 1999 and 1994.
Marine environment	In marine fish the highest organochlorine (OC) levels were found in bottom fish-eating species such as Greenland halibut. In seabirds, the highest OC levels were found in opportunistic feeders such as glaucous gull and in species wintering off North America and Europe such as kittiwake. The highest OC levels in marine mammals were found in narwhals, beluga and polar bear. Considerable evidence now exists of higher OC levels in marine biota from east Greenland than from west Greenland. In general, OC levels in biota from west Greenland were comparable with OC levels found in similar species from east Arctic Canada, whereas biota from East Greenland were intermediate the levels in west Greenland and Svalbard or at the same level as found in Svalbard. Circumpolar patterns of ∑PCB, ∑DDT, ∑CHL in ringed seal, minke whales and polar bears generally increase eastward from east Arctic Canada, west Greenland to east Greenland and Svalbard, whereas the opposite trend was found for ∑HCH. OC concentrations in biota from Qeqertarsuaq showed no consistent changes from 1994 to 1999/2000. In shorthorn sculpin from Ittoqqortoormiit ∑PCB and ∑HCH were significantly lower in 1999/2000 than in 1994. This was also the case ∑HCH in male ringed seals. In polar bears from Ittoqqortoormiit in 1999/2000, ∑PCB and ∑CHL levels were considerably lower than in 1990.

Table 6 Other contaminants of concern. Pécseli *et al*. (2003) analysed a range of compounds not previously included in the Danish AMAP programme. Their conclusions are given in this Table. According to Pécseli *et al*. (2003) the groups of contaminants considered are not *new* strictly speaking. The group of polycyclic aromatic hydrocarbons (PAHs) has for instance been analysed in the environmental samples from Temperate Zone for the last thirty years but data from the Arctic are sparse. Other compounds have not been analysed previously in samples from Greenland.

Other contaminants	
Tributyltin (TBT):	TBT and degradation products were detected in the marine environment in mussels sampled outside Nuuk and in harbour sediments. The TBT levels in mussels were low compared to Danish coastal waters.
Dioxins, furans and coplanar PCBs:	Dioxins, furans and coplanar PCBs were detected in polar bears. Compared to marine mammals in other Arctic regions the concentrations were relatively low.
Toxaphene:	Toxaphene concentrations in the Greenland marine biota were within the range observed in other Arctic regions. Toxaphene levels in Greenland terrestrial biota were lower than in marine biota. The highest toxaphene levels were found in marine mammals especially narwhals.
Chlorobenzene:	The highest chlorobenzene concentrations were found in blubber of narwhal and beluga. The by far dominating chlorobezene in Greenland biota is hexachlorobenzene (HCB).
New chlorinated pesticides:	The highest levels of aldrin, dieldrin, endrin, heptaclor, endosulfan, methoxychlor and mirex were comparable to levels detected elsewhere in the Arctic. Data on levels of endosulfan and methoxychlor, two chlorinated pesticides still in use, in Arctic biota are sparse. The concentrations found were lower than observed in more industrialized parts of the world.
Polybrominated diphenyl ethers (PBDE):	PBDEs are found in all organisms analysed, as a result of not only long-range transport but also local sources. The concentrations measured are lower than found in industrialized parts of the world and below levels that can acutely affect organisms detrimentally.
Polycyclic aromatic hydrocarbons (PAH):	PAH levels in south Greenland are of the same magnitude as levels measured in more urbanized parts of the world, even exceeding the EAC values (OSPAR) for e.g. anthracene. The highest levels were found in fish, e.g. shorthorn sculpin indicating a higher potential for bioaccumulation than seen in the temperate zone.
Contaminants of future concern:	The compound groups PFOS, synthetic musks, polychlorinated naphthalenes, other brominated flame retardants (HBCD, TBBPA and PBB), polybrominated dibenzodioxins and dibenzofurans, aromatic amines and the biocide triclosan are examples of high volume chemicals of high international concern found in the environment at lower latitudes. Studies have indicated the presence of some of these compounds in the Arctic.

Radionuclide pollution

Concentrations of ^{99}Tc, ^{137}Cs and ^{90}Sr in seawater are decreasing in the order North East Greenland and the coastal East Greenland Current > Southwest Greenland > central West Greenland and Northwest Greenland > Irminger Sea ~ Faroe Islands (AMAP, 2002; Riget *et al*., 2003b). This is caused by the general large-scale oceanic circulation combined with European coastal discharges and previous contamination of the Arctic Ocean. The same tendency is seen in marine biota. The peak ^{99}Tc discharge from Sellafield 1994-1995 has only been slightly visible in year 2000. Although, the concentrations are expected to increase in the future, especially in East Greenland, this issue is not considered a problem of concern, and it will have no impact on the biota now or in the future.

On 21 January 1968 a B-52 bomber carrying four nuclear weapons crashed on the ice in Bylot Sound near Thule, North Greenland. The impact triggered conventional explosives, which led to fragmentation of the nuclear weapons on board, and the plutonium spread over the ice. Not all the plutonium was recovered (one bomb is still missing), and an unknown amount fell to the bottom of Bylot Sound. In the plutonium contaminated Bylot Sound, biological activity has mixed plutonium efficiently into the 5-12 cm new sediment resulting in continued high surface sediment concentrations 3 decades after the accident in 1968. Transfer of plutonium to benthic biota is low – and lower than observed in the Irish Sea. This is supposed to be caused by the physico-chemical form of the accident plutonium. A recent study indicates that “hot particles” hold considerably more plutonium than previously anticipated and that the Bylot Sound sediments may account for the major part of the un-recovered amount, i.e. around 3 kg (Riget *et al*., 2003b). However, transfer of plutonium to the biota is low and at present not considered a problem of concern. Riget *et al*. (2003b) recommend that the plutonium contamination should be monitored regularely, e.g. every 5 years.

Oil spills

Oil exploration in Greenland (Sub-regions 1, 15, and 16) is likely in the future. However, the Arctic is particularly vulnerable to oil pollution. The speed with which oil spills disappear depends on the type of oil and various climatic and biological conditions: winds, currents, temperatures, light, and microbial activity (bacteria). Oil is a mixture of hundreds of different carbon compounds. The simplest of them usually evaporate rapidly, but because temperatures in the Arctic are low, evaporation takes place slowly. The oil products used by communities in Greenland is mainly light oils which relatively fast disperse or evaporate if they are spilled at sea, while the worst environmental threat is the heavy crude or heavy fuel oils where oil slicks can persist on the ocean surface or in pack ice for many weeks. Oil spills at sea can be deadly for many animals and large marine spills has the potential to affect sensitive populations (Mosbech *et al*., 1996, 1998; Mosbech, 2002). According to Mosbech (2002), a large spill of crude oil or heavy oil in Greenland could lead to long term contamination of certain habitats.

There is now one offshore oil exploration license and an increased level of offshore oil exploration is expected. In relation to oil exploration, and oil production and transport of crude oil, careful planning of activities and oil spill contingency preparedness can minimize the environmental risk related to oil spills. However, the risk cannot be eliminated and efficient response to an oil spill in heavy seas or in pack ice is still a technological problem. Because of the risk of oil spills one should develop strategies for long term monitoring programs to assess oil concentrations and effects in the environment in case of a spill. This would consist primarily of performing chemical analyses on oil composition and monitoring of oil induced stress on biota.

A Circumpolar assessment of "Petroleum Hydrocarbons in the Arctic" has been initiated by the Arctic Council and is planed to be finished in 2006. It is planned to be a comprehensive and wide-ranging assessment of the environmental impacts of oil and gas developments in the Arctic, and of pollution of petroleum hydrocarbons and PAHs from other sources, also including possible impacts on human health.

Solid wastes

Pollution with solid wastes was locally considered a minor problem in the towns and settlements. It is, however, a problem for most of the towns, and in several of the towns combustion plants have been established in order to reduce the solid waste problem, and instead produce heat for warming of houses. This has contributed to solving one problem, but there have been reporting of local pollution due to fumes and potentially also contaminations with dioxins due to combustion plant management problems, i.e. maintenance of a suitable combustion environment in the oven (Pedersen, 2002).

Similarly ongoing and abandoned military installations and base activities add to the potential pollution level (Glahder *et al*., 2003). Abandoned materials, extensive use of paints with PCB's, and large number of drums with oil residues and undetermined substances both add to the health hazards in connection with cleaning activities, and contaminations of the surrounding environment (Rasmussen and Jensen, 2000; Glahder *et al*., 2003).

Suspended solids

Pollution from mining activities includes contamination in connection with exploration activities, production activities, and due to waste materials from abandoned mines. With only one small gold mine in South Greenland, and most of the exploration activities taking place far from other human activities, they only contribute marginally to the pollution risks. Similarly the abandoned mines only contribute locally to the pollution level and contaminant levels at these are decreasing (Johansen and Asmund, 1999). However, at three closed mines, at which environmental monitoring is conducted, lead pollution from the mining operations (ore, waste rock, and concentrate handling) still is important (Johansen and Asmund, 1999, 2003).

Microbiological
No known impact.

Eutrophication
No known impact.

Thermal
No known impact.

Socio-economic impact

Economic impact

Pollution can seriously affect the economy if natural resources became polluted with contaminants. Greenland's main exporting income is from fish and shellfish export, and an important trademark is the clean products from a pollution free sea. In case of oilspill and other types of contamination this reputation may be threatened and result in much lower prices (Friis and Rasmussen, 1989; Rasmussen, 1998e). At present this is not considered a problem of concern, but future oil spills may have a negative impact on the Greenland economy. However, oil activity also has a positive impact on the economy.

Human health impact

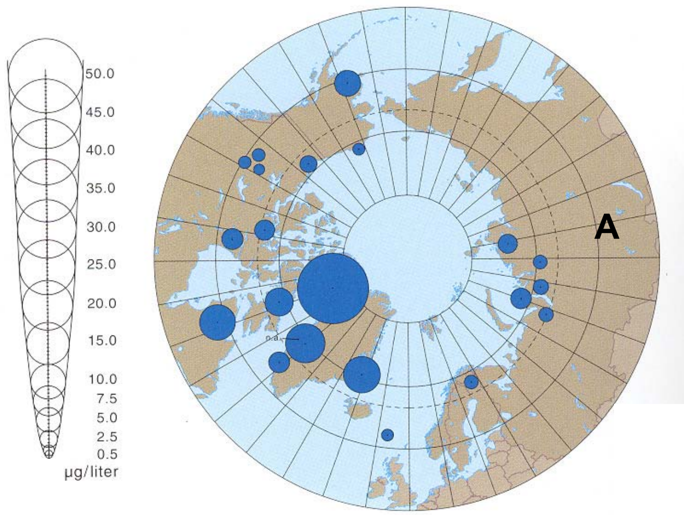
Food is the major exposure route for contaminants in the human Arctic populations. The combination of environmental conditions and biomagnification in the marine food webs result in accumulation of certain persistent contaminants in traditional food of the Greenland people. As a consequence Greenlanders are much more highly exposed through the diet than most populations in the temperate zone (AMAP, 1998, 2002, 2003; Deutch and Hansen, 2003). The AMAP, Human Health, monitoring programme has recently been extended to cover all geographic regions of Greenland (Table 7).

Although levels of mercury (Hg), cadmium (Cd), and persistent organic pollutants (POPs) are relatively low compared to industrialised areas, these compounds are of concern because of their ability to bio-magnify, and because in Greenland marine mammals and seabirds constitute a significant part of the human diet. The cold Arctic climate seems to create a sink for certain pollutant compounds. The high concentrations of contaminants, heavy metals (especially Hg, and Cd), and POPs found in fish, seabirds, marine mammals, and humans, causes concern for animals and human health in Greenland (Fig. 8). The present levels of mercury and some POPs in sea animals have a negative effect on the health of Greenlanders, because these animals are an important part of their diet (Grandjean *et al*., 1998; AMAP, 2002, 2003; Deutch and Hansen, 2003).

In Greenland, diet is the main source of exposure to most contaminants. Dietary intake of mercury and PCBs exceeds established national guidelines in a number of communities in Greenland, and there is evidence of neurobehavioral effects in children in some areas of the Arctic. In Greenland, a local public health intervention has achieved a reduction of exposure to mercury by providing advice on the mercury content of available traditional foods. The physiological and nutritional benefits of traditional food support the need to base dietary recommendations on risk-benefit analyses. The health benefits of breast-feeding emphasize the importance of local programs that inform mothers how adjustments within their traditional diet can reduce contaminant levels in their milk without compromising the nutritional value of their diet.

Table 7 Human Health impacts of contaminants in Greenland (Deutch and Hansen, 2003).

Human health
A geographical survey has revealed that the highest human blood levels of POPs in particular of PCB are to be found in East Greenland, with close to 100 % in excess of the Canadian blood-guidelines for PCB-aroclor1260 for both men, women of fertile age, and pregnant women. Exposures to methyl mercury are more geographically uniform. In several areas close to 100% of the samples exceed the blood concentration corresponding to the strict US-EPA guideline and a considerable part also exceeds the WHO guidelines. Selenium gives some protection against the toxic effects of some forms of mercury. Selenium intake through the diet is high among Greenlanders, however, there is at the moment not sufficient information on a protective effect against POPs and methyl mercury. It has so far not been possible to assess time trends in POPs exposure, due to too short an observation period. There are no indications of declined exposures to methyl mercury, whereas the blood levels of lead are continuing to decrease. New data on contaminant concentrations in animals used for food, in combination with improved dietary surveys have made exposure estimates possible with identification of species and organs with the highest contributions to human exposure. On country wide basis seal blubber followed by whale blubber are the predominant sources of POPs whereas seal meat is the main source of methyl mercury. However, in areas where polar bear is consumed that can be a major additional source of POPs. It is known that POPs negatively influence the immune system. As the exposure to POPs in some Greenland districts is among the highest ever measured it is reasonable to expect an influence on the immune status in these populations. As POPs are only one of several influential factors, causality is difficult to establish in these small populations. There is no epidemiological evidence from Greenland to correlate pregnancy outcomes, neonatal mortality, or prevalence of infectious diseases to POP exposure. No overt health effects of endocrine disrupting POPs have so far been confirmed. The exposure level is very high in some communities, in excess of e.g. Canadian guidelines. Because the possible effects should be viewed in a perspective of several generations the present situation warrants public health measures to be taken in order to reduce the exposure without jeopardising the nutritional values of the traditional diet.



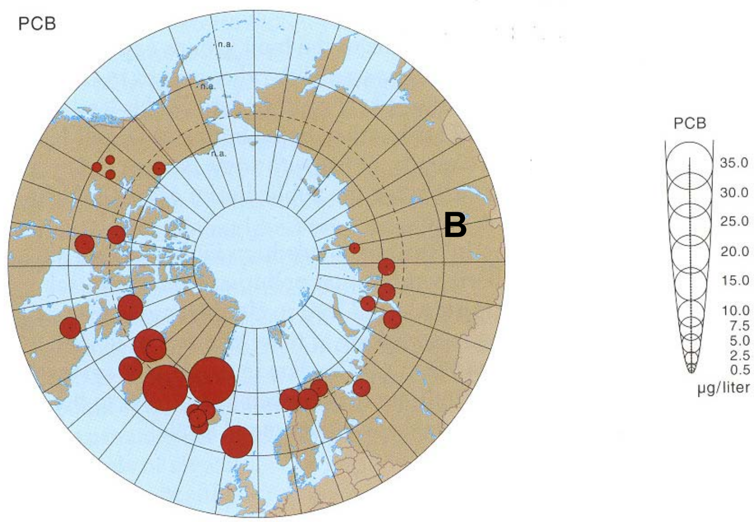


Figure 8 Mercury (A) and PCB (B) concentrations in human blood (Source: AMAP, 2002).

Other Social and Community Impacts

A suggested change in diet to reduce human contaminant intake will affect lifestyle and culture of people in Greenland (see Deutch and Hansen, 2003).

Conclusions and future outlook

For the Major Concern *Pollution* as a whole, the present levels of environmental impact were considered to be of a moderate degree. A major concern is long range transport of contaminants, which are bioaccumulated in tissues of animals, and because these are important local diet items, both animals and human health might be affected.

Over the next 20 years, environmental and human health impacts from pollution are considered to remain moderate or to be increased, unless strict regulations and internationally adopted environmental protection measures are implemented (see The Arctic Monitoring and Assessment Programme: Recommendations in AMAP, 2002, 2003).

Over the next 20 years pollution of radio-nuclides and oil spill have a potential to increase, e.g. due to leakage from radioactive waste stored in interim depots (outside Greenland) and offshore oil activities, respectively. Increasing shipping, oil exploration, and the transport of oil have heightened the risk of oil spills. Other local environmental pollution issues were considered of no or little concern today and in 20 years.

2.3. Major Concern: Habitat and community modification

To the task team experts, losses of ecosystems or ecotones, were considered to be of no or slight impact in the three Greenland sub-regions. Since the two issues are closely connected, the assessment focused on the modification of ecosystems or ecotones. This issue was considered to have a moderate environmental impact.

Environmental impacts

Global climate change

The recent significant reduction in sea ice cover in East and North Greenland and the increase in ice cover observed in some areas of West Greenland are most probably related to warming and global climate change (Serreze *et al.*, 2000; Johannesen *et al.*, 2002; Stern and Heide-Jørgensen, 2003). Increased open water period will increase annual pelagic primary production and food production for higher trophic level animals in a wide range of Arctic marine areas (Rysgaard *et al.*, 1999, 2003).

The reduction in sea ice and increased open water period may be a benefit to some marine mammals e.g. Atlantic walrus which may get improved feeding conditions (Born *et al.*, 2003). However, polar bear may have reduced habitats and feeding areas (Wiig *et al.*, 2003).

2.3.1 North and East Greenland (Sub-region 1 and 15)

In Northeast Greenland the expected global warming is predicted to result in severe changes and in reductions of ice thickness and prolonged open-water periods – up to halving in the fjords and a doubling of the ice-free period (Johannesen *et al*., 2002; Ryesgaard *et al*., 2003). As a result, more light will penetrate down in the water column, which will stimulate the production of both plankton algae and bottom-living algae. However, the increased precipitation (snow) will impair the light conditions in the ice in early spring and probably have an adverse effect on the production of sea-ice algae and the animals that benefit from the early production. All in all, however, production is predicted to increase (Rysgaard *et al*., 1999, 2003; Meltofte *et al*., 2003).

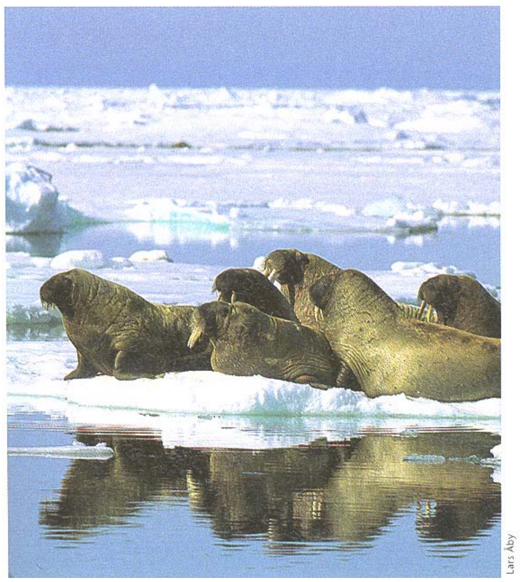


Figure 9 Walruses occur in coastal waters. They often rest on small, sturdy ice floes. Thus, these floes are part of their habitat. From Born and Böcher (2001).

Algae, water copepods, mussels, and walruses

An increased fresh water supply as a consequence of increased precipitation and melting of the ice cap in the inner parts of the fjords is likely to increase the water exchange in the fjords and bring more nutritious water in from the open sea and thus contribute still further to increased primary production. The increased production is predicted to have a powerful effect in the top levels of the food chain. Today, water copepods (crustaceans that live on algae) are limited by food (Rysgaard *et al*., 2003), and stimulation of plankton production will immediately mean increased grazing and growth of copepods).

Sedimentation of the copepods' faeces will therefore increase, thereby increasing the quantity of food for bottom-living animals. This will, for example, increase growth in mussels, which are today very limited by food. The increased mussel growth will benefit for example walruses (Born *et al*., 2003). Rising winter temperatures will mean that the ice does not reach the same thickness as today and will therefore break up earlier in spring and that the walruses could seek food on the mussel banks for longer periods.

Problems for polar bears

The polar bear, on the other hand, is facing an uncertain future in East Greenland. The effects of global warming on East Greenland polar bears have not been documented. However, with reference to what has been found in other parts of the Arctic (e.g. Hudson Bay and Svalbard) polar bears in East Greenland may be negatively affected (Lunn *et al.*, 2002; Wiig *et al*., 2003). In areas where the ice disappears fast it reduces the bears' hunting grounds and the bears' will probably follow the ice northwards. However, another possible scenario is that starving bears seek land and become an easy hunting target for bear hunters (E.W. Born, Greenland Institute of Natural Resources, pers. comm.). Seals, which are attached to the ice, will presumably become concentrated in smaller areas with ice and may therefore be more easily accessible to the bears, but in the longer term, the number of bears will decrease. In addition, the polar bears are not good at hunting seals in water.

Figure 10 Polar bears live in ice-covered fjords and seas, their most important prey being ringed seals. It has been estimated that the polar bears of Baffin Bay and Davis Strait eat about 160,000 ringed seals each year. From Born and Böcher (2001).

Fish

Rising surface temperatures will also have a major effect on the composition of fish in the high-Arctic zone (i.e. sub-region 1). In the case of Arctic char, reproduction ceases when the temperature rises above 5°C because the enzymes in the egg sacs denature when the temperature is just a little over 5°C. As a result, the eggs rot in the body and the fish dies. At the same time, a number of Arctic fish species will be more exposed to parasites and bacterial and fungal attack, and their immune defense system will be reduced with rising temperatures.

Crabs, copepods, and sea birds

There are no crabs in areas with temperatures below 0.5ºC, which characterizes large areas off East Greenland. The temperature rises in the future will perhaps mean that crabs will migrate into the area and thus distinctly change the composition of bottom-living fauna. According to Soto (2002) temperature directly affects the metabolic rate and other physiological features such as growth rate and incubation time on invertebrates and fish. Increased temperatures increased growth rate, while decreasing incubation time (Soto, 2002), the direct effects of temperature on the species will change species compositions in the systems.

Another marked change that could happen is a change in currents, so that North Atlantic sea water containing a smaller species of copepod (*Calanus finmarchicus*) could penetrate areas that are today dominated by polar water with larger and longer-living species of copepod (*C. glacialis and C. hyperborus*). If *C. finmarchicus* ousted the larger species it will have very serious consequences for little auks, which breed in millions in the Thule area and around Scoresbysund, and which are specialised in foraging along the edges of ice with high concentrations of food animals (Egevang *et al*., 2003). The little auk lives almost exclusively from the large species of copepod and can probably not sustain on the smaller species (Egevang and Falk, 2001). Conversely, the Atlantic guillemot may be able to immigrate in large numbers, just as a number of other sea bird species may benefit from the increased marine production and the reduced ice cover.

2.3.2 West Greenland (Sub-region 16)

Sea ice and open-water refugia are of crucial importance for marine productivity and the occurrence, distribution and abundance of sea birds and marine mammals in the Arctic marine ecosystems of the Northwest Atlantic (Heide-Jørgensen and Laidre, 2004). The timing and extent of primary production is strongly related to the ice formation. Late break up of sea ice may delay phytoplankton production and modify connections between phytoplankton and copepod grazers that ascend from the depth at specific times of the year. In Disko Bay, West Greenland, the behavioural adaptations of *Calanus* spp. to climate change may have strong effects on the food web structure, generating trophic cascades and eventually influence sea birds, marine mammals, and the fisheries (Hansen *et al.*, 2003). The cascading effects of sea ice coverage and marine productivity on the Arctic trophic web is difficult to assess in remote areas. According to Heide-Jørgensen and Laidre (2004) both the cetaceans (Bowhead whales, narwhals, and belugas) and sea birds (king and common eider, little auk, thick-billed murre) are vulnerable to an increase in sea ice and decrease in open water, as observed during the last decades. For example the migrating cetaceans are vulnerable to decreased open-water because they need oxygen after dives that can rarely exceed 25 minutes (Heide-Jørgensen and Laidre, 2004).

Fish and shellfish

In the last 30 years, cod and a number of other boreal fish species in South and West Greenland marine waters have decreased substantially as a consequence of generally colder climate combined with unsustainable exploitation. Today, more cold-adapted populations of shrimp, crab, and halibut constitute the main commercial fishing resources in Greenland (Buch *et al*., 2003). A change in sea currents and a rise in temperature as a consequence of the climate changes are assumed to improve the conditions of life for cod and other boreo-atlantic commercial fish species in Southeast and West Greenland, while impeding arctic species such as Greenland halibut. In addition, a larger cod population will most probably reduce the shrimp population due to predation (e.g. Pedersen, 1994a,b; Pedersen and Zeller, 2001; Hvingel, 2002a). It can therefore be envisaged that there will be a change in the fishing resources from today's dominance by shrimp to dominance by cod under a warmer ocean climate.

Resource exploitation

Modification of bottom habitats and community structures in Southeast and West Greenland due to bottom trawl fishery was seem as an environmental problem. The bottom trawl fishery for shrimp in the Davis Strait, West Greenland, is one of the world's largest cold water shrimp fisheries, with an annual catch of about 80,000 tons in recent years, corresponding to an area of 16,000 km^2 trawled each year. From other areas of the North Atlantic e.g. direct and indirect effects of fisheries on marine ecosystems has been reported as a major concern (see e.g. Svelle *et al*., 1997). However, in Greenland no or little data exists to evaluate the extent of e.g. modification of bottom habitats and community structures due to fisheries.

Human disturbance of breeding sites for seabirds was also seen as a threat to local seabird populations. Hunting affects seabird populations not only by killing birds. Delayed effects on fitness may arise due to embedded shots and disturbance factors, such as disruption of breeding activities, interrupted feeding opportunities, displacement from preferred feeding habitats, and increased energetic expenditures due to flying – which eventually may affect body condition and subsequently reproductive success (Merkel, 2002a).

There is no documentation where disturbance impacts on seabird populations breeding in Greenland have been separated from hunting impacts. But experience from other areas show that disturbance is closely linked to hunting activities, both in terms of the activities as such, and also in terms of how birds react to disturbance (e.g. Fox and Madsen 1997, Madsen 1998). Therefore disturbance impacts will be dealt with elsewhere.

Socio-economic impact

Economic impact

Large scale tourism development is generally absent in Greenland, except maybe for Disko Bay where several research projects assess the environmental impact of tourism that has been increasing rapidly over the past few years. Two other existing forms of tourism are expensive tourism in the hunting districts on the one hand, mainly interacting with specially developed services mimicking the traditional hunting communities (Danielsen *et al*., 1998), and hiking tourism mainly in South Greenland, often connected to rod fishing and farm stays, supplying an additional income to sheep farmers. These services appear not to be influenced by changes in resource usage patterns (Rasmussen and Hansen, 2002). According to Kaae (2003) there is a need for improved interactions between tourism, management of natural resources, and the local societies in Greenland.

Health impact

No known impact.

Other Social and Community impacts

No known impact.

Conclusions and future outlook

The knowledge about the way the water ecosystems function is constantly improving, but to predict the biological impacts of the large scale reductions in ice cover etc., observed in the East Greenland Shelf ecosystems in summer 2002 and 2003, more knowledge on the coupling between physics and biology is needed. These fast changes in the habitats for the Greenland biota will have a high impact on life cycles, productivity, and probability of survival for all animals e.g. polar bears and walruses.

One of the biggest uncertainties in connection with the marine environment in South Greenland is the extent to which the sea currents and thus sea temperatures follow changes in air temperature. The balance between the part of the seawater in Southwest Greenland that comes from the cold East Greenland Current and the warm Irminger Current, and the cold water masses in Baffin Bay and Davis Strait, thus totally determine the ecological conditions off Southwest Greenland, where most of Greenland's human population live.

In conclusion there is a need for development of coupled climate-ocean-biological models and ecosystem based management of natural resources in Greenland waters. A research programme to establish a scientific basis for a long-term ecosystem-based management of natural resources in West Greenland waters was outlined in 2001 (Jarre, 2002). This programme is currently under development and planning by the Greenland Institute of Natural Resources and several other international partner institutes (Greenland Institute of Natural Resources, 2002).

2.4. Major Concern: Unsustainable exploitation of fish and other living resources

Environmental impacts

Over-exploitation

Fishing

In West Greenland, over-exploitation has been reported for Atlantic cod, Atlantic halibut, redfish, wolfish, starry ray, long rough dab (e.g. Buch *et al*. 1994; ICES, 2003; NAFO, 2003; Greenland Institute of Natural Resources, 2000). In East Greenland, over-exploitation has been reported for Atlantic cod, Greenland halibut, and redfish (ICES, 2003).

Many of the Greenlands fish resources are unstable because temperature limits their distribution. Even small changes in ocean circulations and sea temperatures can have profound effects on species productivity and distribution (see causal chain analysis). At present cod is very sparse in both offshore and inshore areas of West Greenland. ICES recommends no fishing on cod until a substantial increase in recruitment and biomass is evident (ICES, 2003). According to ICES (2003), a recovery plan for both inshore and offshore components should be developed in order to take advantage of strong year classes when they occur and to protect all inshore spawning components. For other fish species such as redfish, wolfish, starry ray, and long rough dab, NAFO similarly recommends no fishing until a substantial increase in recruitment and biomass is evident (NAFO, 2003).

Sea bird hunting

Several species of seabird populations belonging to the West Greenland ecosystem, Brünnich's guillemot, king eider, common eider, and Arctic tern have been reduced due to human activities, and in most cases hunting, egg collection, and associated disturbance has been assigned as the main impact factors (Frich, 1997; Mosbech *et al.*, 1998; Jensen, 1999; Falk and Kampp, 2001; Merkel and Nielsen, 2002; Merkel *et al.*, 2002; Merkel, 2002a,b; Egevang and Boertmann, 2003; Greenland Institute of Natural Resources, 2000). Catch statistics are given in Table 8.

Table 8 Reported number of individuals by part-time and full-time hunters, 1996-2000 (Source: Namminersornerullutik Oqartussat, 2002).

	1996	**1997**	**1998**	**1999**	**2000**
Sea Birds					
Brünnich's guillemot	254728	236466	221783	227121	176760
Common eider	83810	76991	72109	71041	61702
King eider	5557	4030	3362	3535	2684
Little auk	64494	49220	21017	25296	44871
Small whales					
Narwhal	738	797	822	775	597
Beluga	542	577	746	493	609
Harbour porpoise	1682	1550	2051	1830	1607
Pilot whal	67	208	365	115	5
Seals					
Ringed seal	90309	80387	82108	83453	80265
Harp seal	74945	69663	82491	95097	99847
Hooeded seal	9906	7500	6328	7458	5834
Bearded seal	2134	2349	2354	2336	2695
Habour seal	256	295	217	148	124
Walros	305	317	610	311	329

At least 57,000 common eiders are bagged annually in Greenland, which corresponds to app. 12% of the total winter population estimated for West Greenland (Merkel, 2002a). According to a population model (Gilliland *et al.* in prep.; Merkel, 2002a) the West Greenland winter population can sustain a take of app. 8%. As a consequence of the over-exploitation, the model predicts the West Greenland breeding population to decline by 3.2% per year, which is close to survey figures detected at some breeding grounds.

Beluga, narwhal and walrus hunting
In West Greenland the declining abundances of walrus, narwhal, and beluga are believed to be mainly caused by over-exploitation (Born *et al*., 1994; Greenland Institute of Natural Resources, 2000; Heide-Jørgensen, 2001; Heide-Jørgensen and Acquarone, 2002). Catch statistics are given in Table 8.

Of marine mammals the reductions in the Northwest Greenland beluga population have caused concern (Table 9).

Tabel 9 Calculated number of belugas in the area Qeqertarsuaq og Maniitsoq, West Greenland. From aerial observations (Source: *Greenland Institute of Natural Resources*, www.natur.gl).

Year	**Number of belugas**
1982	19,689
1994	10,230
1999	7,941

Excessive by-catch and discards

Fish
In addition to reported landings one will have to add an unknown amount of unreported fish and shrimp catches discarded at sea. Large amounts of small fish, especially redfish, are discarded or die due to contact with the fishing gear in the sea (e.g. Pedersen, 1995).

Although little quantitative information on the by-catch and discards of fishes in the West Greenland shrimp fishery is available, the considerable fishing effort of shrimp fishery (e.g. 164,000 trawl hours in 2001, see Hvingel, 2002b) seems to affect the demersal fish community (Buch *et al*., 2003; Siegstad *et al*., 2003a,b).

Sorting grids (22 mm) have, however, been mandatory in the shrimp fishery since October 1, 2000, in order to reduce the by-catch of juvenile fish. Results of experimental fishing with 22mm sorting grids shows a nearly complete protection to finfish larger than about 20 cm, but poor protection of the smallest fish (Engelstoft *et al*., 2001). Besides the introducing of sorting grids Greenland shrimp trawling regulations require ships to change grounds by at least 5 miles as soon as by-catch exceeds certain limits. To reduce by-catch and discards in e.g. the Greenland Commercial shrimp fishery, the Greenland Home Rule Government has introduced by-catch regulations and laws, and inspectors onboard large trawlers to ensure that the fishing laws and regulations are enforced.

In 2003, ICES advises that technical measures to avoid the by-catch of juvenile cod in the shrimp fishery should be maintained (ICES, 2003). This advice was partly based on a cod recruitment model which indicates a significant effect on potential stock recovery of even low fishing mortality on pre-recruits.

Sea birds
Current studies indicate that by-catch of eiders in gillnets is a problem during late winter and spring in southwest Greenland. In Nuuk around 16% of all eiders sold at the local market in 2000/2001 originated from gillnet by-catch (Merkel pers.com). Nearly all the by-catch came from the lumpsucker fishery in March and April.

There is also an unaccounted mortality of seabirds wounded by gunshots but not retrieved during hunting. The number of wounded birds, which later die of the wounds is unknown. However, that wounded birds is not uncommon is indicated by the estimate that about 30% of the adult eiders caught as by-catch in gillnets in Nuuk Fjord carry lead pellets from gun shots (Merkel, *pers. comm*.)

Destructive fishing practices

The high effort of bottom trawling in the Greenland shrimp fishery was considered to have a moderate environmental impact. The main concern was modification of bottom habitats and community structures due to bottom trawl fishery. However, to date no data exists to evaluate the extent of modification of bottom habitats and community structures.

Decreased viability of stock through pollution and disease

In spite of the considerable degree of chemical pollution detailed above, this is at present not a problem of concern for Greenland.

Impact on biological and genetic diversity

Not known – no data.

Socio-economic impact

Economic impact

There was some discussions and doubt about the economic score impact of over-fishing and discards of small fish and shellfish in the bottom trawl fishery. Bycatch and discard data are largely missing However, based on very preliminary trophic modelling and comparisons with experience in similar systems, e.g. the Newfoundland shelf, it was judged that there was a moderate economic impact (score 2) of by-catch of small fish and shellfish in Sub-region 15 and 16.

The fisheries in Greenland are characterized by three main sectors with distinct differences between large scale offshore, intermediate and small scale inshore activities. This is not only due to structural and economic patterns, but also caused by political relations of importance for the country's development process. A series of social science studies related to the Greenland fisheries sector were carried out in the 1980s (e.g., Winther, 1988; Roth 1988; Roth 1989; Vestergaard and Christensen 1993; Vestergaard et al. 1993), and business cultures, particularly related to the political wish for further independence, of Denmark, have recently been analysed (e.g., Winther, 2000, 2001).

The large scale sector dominated by a capital rationale, with concentration and centralization through large-scale projects and economy of scale as the fundamental mechanisms, giving access to resources otherwise inaccessible, and the major contributor to the national economy.

The intermediate sector of the regional fisheries, partly based on capital rationality, and partly based on a life form which has become a backbone of many of the larger settlements, but also present in many smaller settlements. This sector is important for the regional economies.

Greenland does not *a priori* appear to be an exception to the general pattern of potentially excessive effort. Continued renewal of the coastal fleet is constantly being discussed in public despite decreasing prices for northern shrimp, and rapidly increasing effort has been documented, e.g., in the fisheries for Greenland halibut and snow crab. In a large, sparsely populated country, incentives that increase the probability of rule compliance have been recognised of overriding importance to the implementation of a management system (e.g., Heilman 1998).

The small scale sector, relying on small boats, dog-sledges and/or snowscooters, is vital for the small settlements, and constituting the backbone of the cultural heritage, and important for the direct and indirect political attempts to maintain reasonable living conditions for the smaller places. At the same time its contribution to the maintenance of the informal and subsistence sector is certainly not negligible (Rasmussen, 1998c; Caulfield, 1997; Marquardt and Caulfield, 1995).

A general obstacle to a rational evaluation of the different scales of activities is the way the economy of the different sectors of fisheries is perceived. An evaluation of the total output per person (output=Dkr) involved in fisheries (Rasmussen, 1994) demonstrates the dominance of the off-shore fisheries with an outcome 10 times the medium scale fisheries and 200 times the output of the small scale fisheries. But an evaluation of the output in relation to the invested capital shows a very different pattern, with the off-shore sector as the least capital efficient activity, the small scale fisheries being ~1½ times more efficient than the off-shore sector, and the medium scale fleet the most capital efficient activity being ~2½ times more efficient than the off-shore sector (Rasmussen, 1998a; Rasmussen *et al.*, 1998; Rasmussen, 2000a).

A review of the economic development in Greenland focussing on ownership and economic systems suggests that the performance of the economy has not been that bad after all, and that purely market-driven systems do not appear to be a viable solution for the Greenland economy (Winther, 2000). This study suggests that be the future of economic grow may be found in a mix of public, hybrid and private ownership, and this can already at present be combined with a multitude of owners and organisational forms. Although the potentials of participatory ownership are emphasized and elaborated (Winther, 2001), concrete examples also exist that highlight the gap between private and co-operative interest in a developing context (Olsen, 2001).

Health impact

No known impact.

Other Social and Community impacts

Unsustainable fishery and hunting may lead to 1) unemployment, social, cultural, and economic loss (e.g. Hamilton *et al.*, 2000; Rasmussen and Hamilton, 2001), 2) changes in human diet and lifestyle, and 3) tourism may also potentially be adversely affected, because many tourists expect to see a well-managed, relatively unspoilt nature in Greenland with plenty of wildlife – typically species that are top predators in the respective food webs (Kaae, 2003).

Conclusions and future outlook

The task team experts found unsustainable exploitation of fish and other living resources to have severe impact in East Greenland Shelf (15) and West Greenland Shelf (16), but no impact in Arctic North Greenland (1).

Over-exploration and by-catch of fish and shellfish in South Greenland (Sub-region 15 and 16) were assessed to have moderate economic impact.

In a preliminary analysis, the Danish government's Advisory Committee on Greenland's Economy, emphasises the importance of optimising the fishery policy in Greenland from a national economics perspective and list a number of issues for which a balanced solution needs to found, e.g. maximising economic efficiency, safeguarding employment and cultural values (Det rådgivende udvalg vedrørende Grønlands økonomi, 2002). A more detailed analysis is presently carried out.

A comprehensive research programme into the structure and functioning of the marine ecosystem in West Greenland, including both natural and social sciences, is currently being developed (Jarre 2002, Greenland Institute of Natural Resources 2002, and see below) in order to contribute towards improved management of human activities in the respective ecosystems.

Modeling and predicting the optimal outcome of exploitation of marine resources depends on many factors of which some of the most important are to be found in good/adequate knowledge about resource dynamics, exploitation (fishing/hunting, technology, gear) and socio-economics. This knowledge is especially important for the Greenland society facing changing climatic conditions, because the dynamics and productivity of marine resources, which the Greenland depends upon, follows climatic conditions. The dynamic impact on the two main forces on the marine resources, 1) climate and 2) exploitation, are not well described and addressed in the present management of Greenland's marine resources.

2.5. Major Concern: Global change

Environmental impacts

Changes in oceanography

Global changes in climate, oceanography, and sea ice, and the possible impacts on marine biota in Greenland have been described and addressed in e.g. Smidt (1989); Heide-Jørgensen and Johnsen (1998), Buch *et al.* (2001), Petersen *et al.* (2001), Rudels *et al*. (2002), Johannesen *et al*., (2002), Buch *et al*. (2003), Meltofte *et al.* (2003), Hansen *et al.* (2003), Stern and Heide-Jørgensen (2003) and Heide-Jørgensen and Laidre (2004). The influence of global change on contaminant pathways to, within, and from the Arctic has been described in Macdonald *et al.* (2003).

Changes in atmospheric pressures over the past 3-4 decades have caused changes in ocean circulation, water temperatures, sea ice extent, etc, which have generated changes in the marine ecosystems of Greenland.

These changes have been most clearly seen in the changes in the exploited natural resources - from mainly cod fishery before 1970 to a gradually increasing shrimp fishery after 1970 - reflecting a shift in the ocean climate from generally “warm” conditions before 1970 to generally “cold” conditions after 1970 (Fig. 11).

The oceanographic and sea ice conditions around Greenland are linked to climate variability and the changes in the distributions of atmospheric pressures on the northern hemisphere. The *North Atlantic Oscillation Index* (NAO-index) play an important role in forming the climate in the North Atlantic region (Hurrell, 1995; Dickson et al., 2000). The phase of the NAO has important effects on climate throughout the North Atlantic. During positive phases, the planetary westerly winds intensify, and the North Atlantic storm track shifts to the north. These changes lead to milder conditions in the western Atlantic and east coast of the United States; colder, stormier conditions in the northwest Atlantic and Greenland; and milder conditions in the northeast Atlantic and coasts of northern Europe and Great Britain. In contrast, during negative phases of the NAO, the westerly winds diminish in intensity and the storm track shifts to the south. These changes lead to colder, stormier conditions in the western Atlantic and east coast of the United States; milder conditions in the northwest Atlantic and Greenland; and colder, drier conditions in the northeast Atlantic and coasts of northern Europe and Great Britain.

The winter (December-March) NAO-index tends to be positively correlated with next year’s winter sea ice concentrations in West Greenland, but negatively correlated with next year’s sea ice concentrations in Northeast Greenland (Stern and Heide-Jørgensen, 2003).

The warming of the northern hemisphere during the last decades has given reduced summer ice cover and increased open-water periods in East Greenland, however, at the same time regional lower temperatures, increased ice cover, and reduced open-water periods have been observed in West Greenland. These changes have major impacts on species distributions and fisheries as described under
1.1. Physical characteristics of Greenland and 2.3. Major Concern: Habitat and community modification.

Sea level change

Only one water level (WL) recorder in Nuuk, West Greenland, has measured WL over a long period. A slight increase in WL since 1960 has been registered, but it is insignificant and of no importance for Greenland (E. Buch, Danish Meteorological Institute).

Increased UV-b radiation as a result of ozone depletion

UV-b mesurements have been made in Greenland over several years. Changes in ozone concentrations have been compensated by an increase in cloud cover and there have therefore been no changes in the UV-b radiation.

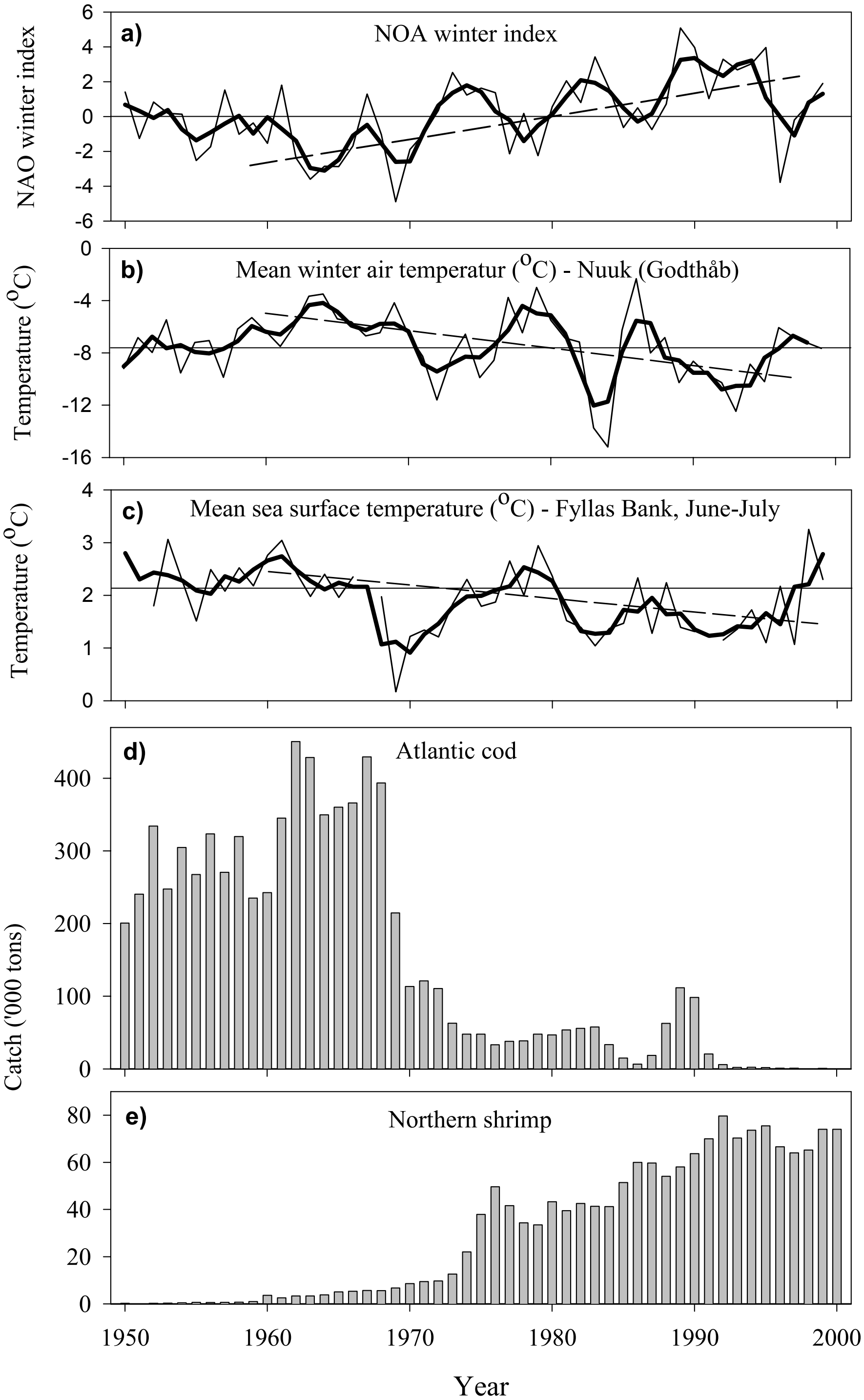


Figure 11 Time series of the winter NAO index (a), winter air temperature (b), sea temperature (c), landings of Atlantic cod (d), and northern shrimp (e) in the West Greenland LME (16), 1950-2000 (Source: S.A. Pedersen, Greenland Institute of Natural Resources, unpubl.; redrawn from Petersen *et al*., 2001).

Changes in ocean CO_2 source/sink function

The east and west Greenland shelf areas (region 15 and 16) and the Arctic ocean (region 1) are remote areas with few observations of the marine carbon chemistry. However, the open ocean area in the Nordic Seas are one of the globally most efficient regions per area in sequestering CO_2 from the atmosphere (e.g., Takahashi *et al.*, 2002), and therefore significant changes would be expected in the near shore surface pCO_2 field around Greenland and in the Arctic ocean as a consequence of global change, in particular the rising atmospheric CO_2 level. Therefore the assessment is: Some reasonable suspicions that current global change is impacting the aquatic system sufficiently to alter its source/sink function for CO_2.

Socio-economic impact

Economic impact

The interactions between climate and human resource use have large socio-economic impact. The combination of climate variation and fishing pressure, for example, proved fatal to West Greenland's cod fishery (e.g. Smidt, 1989; Buch *et al*., 1994; Horsted, 2000; Hamilton *et al*., 2000). The socio-economic consequences may differ substantially due to different response patterns, both regionally and sectoral (Rasmussen and Hamilton, 2001). The resilience of the social systems, however, may contribute to solving some of the adverse effects of climate change, for instance enabling a continuous consumption of traditional food products, in spite of attempts to globalize the consumption patterns (Rasmussen, 2002; Rasmussen, 2003 forthcoming).

Health impact

No known impact.

Other Social and Community impacts

For the Greenland society, a warmer climate would probably mean increased fishing in the form of more boreo-atlantic species such as cod, and haddock, but fewer shrimps. The possibilities for hunting ring seals and polar bears would probably be reduced in the long run, while the occurrence of several other game animals would depend more on the pressure of hunting itself. Transport conditions would be much better because the period of open water would be longer, making it easier for boats to call at many towns and villages. There would probably be far less field ice, but on the other hand, a reduced possibility of using the ice to get from place to place. Retraction of glaciers and the ice cap, together with less "Arctic wilderness" could adversely affect the tourist industry, but the improved communication – including a longer summer season – could have a beneficial effect.

Conclusions and future outlook

The task team assessed a moderate impact of global change in the High Arctic, North Greenland (1) and a slight impact in East – (15) and West Greenland (16). The Arctic is vulnerable to global environmental threats, such as the greenhouse effect. Even small changes in average temperatures will probably have profound consequence in an environment where many organisms are adapted to specific distribution patterns of ice.

Although climate change was assessed to have slight impact in East- and West Greenland, decadal climate variability is a very important factor for the distributions and productivity of Greenland's natural renewable resources. Climate is a driving force for habitat modifications and linked to over-exploitation of resources and pollution.

In the 20th century Greenland has experienced two great transitions, from seal hunting to cod fishery, then from cod to shrimp fishery, both affected the human population centers of West Greenland and the economy. The economic transitions reflected large-scale shifts in the underlying marine ecosystems, driven by interactions between climate and human resource.

Model predictions of future climate change and its impact on the habitats, communities, living resources, pollution, and socio-economics are needed for Greenland.

2.6. Priority of major concern issues for future analysis

The result of the impact assessments of GIWA issues in the three Greenland sub-regions are summarizes in Table 10.

Table 10 Prioritization of impacts of Major Concern at present and in 2020 in Arctic Ocean (1), East- and West Greenland Shelf (15 and 16).

Major Concern	**Impact/ Present**	**Impact/ 2020**	**Overall Score (Sum -weight%)**
Arctic North Greenland (Sub-region 1)			
I Freshwater shortage	No known (0)	No known (0)	**0**
II Pollution	Moderate (2)	Slight (1)	**3 - 10%**
III Habitat and community modification	No known (0)	No known (0)	**0 - 45%**
IV Unsustainable exploitation of fisheries	No known (0)	No known (0)	**0**
V Global change	Moderate (2)	Moderate (2)	**4 - 45%**
East Greenland Shelf (Sub-region 15)			
I Freshwater shortage	No known (0)	No known (0)	**0**
II Pollution	Severe (3)	Slight (1)	**4 - 30%**
III Habitat and community modification	Slight (1)	Moderate (2)	**3 - 10%**
IV Unsustainable exploitation of fisheries..	Severe (3)	Moderate (2)	**5 - 30%**
V Global change	Slight (1)	Slight (1)	**2 - 30%**
West Greenland Shelf (Sub-region 16)			
I Freshwater shortage	No known (0)	Slight (1)	**1 - 0%**
II Pollution	Moderate (2)	Moderate (2)	**4 - 20%**
III Habitat and community modification	Moderate (2)	Moderate (2)	**4 - 10%**
IV Unsustainable exploitation of fisheries..	Severe (3)	Moderate (2)	**5 - 50%**
V Global change	Slight (1)	Slight (1)	**2 - 20%**

The environmental factors were considered to be far most important and the sum of present and future score were used as the overall score of Major Concern (0 lowest and 5 highest overall score).

Habitat modification and overexploitation at West Greenland Shelf (16)
Far most of the Greenland population lives on the west coast of Greenland, about 53,000 people. “Unsustainable exploitation of fisheries and other living resources”, “Pollution” and “Habitat and community modifications” were assed to have severe and moderate impact, respectively. Over-exploitation and chemical pollution were given high priority issues partly because harvesting the natural resources is the backbone of the Greenland society and culture. In addition fishing and hunting are the main or only income for many Greenlanders.

Chemical Pollution at East Greenland Shelf (15)
East Greenland is inhabited by only about 3,600 people. “Pollution”, “Unsustainable exploitation of fisheries and other living resources”, and “Habitat and community modifications” were assed to have severe and moderate impact, respectively. The system was assessed severely impacted by the issues chemical pollution and over-exploitation by offshore fishing vessels from West Greenland and foreign countries.

Chemical pollution was considered to be a high priority problem because contamination of the Greenlanders natural food sources (fish, sea birds and marine mammals) causes human health problems and changes in the Greenlandic life style.

Habitat and Community modification in Arctic North Greenland (1)
Although **"**Habitat and community modification" was given zero score at present and in 2020, **"**Habitat and community modification" caused by climate change was considered to be high priority issue under both present and future conditions. The reduced ice-cover and increased open water period in Northeast Greenland and vice versa for Northwest Greenland most probably have a profound impact on the ecosystem dynamics and the unique high Arctic biota (e.g., polar bear, beluga and walrus). However, at present much too little information exists to document these impacts and changes. There is therefore a need for continued and increased research.

Major concern issues were the future changes in climate, melting of sea ice, ice cover, ocean circulation, and the resulting effects on biota, habitats, contamination and ecosystem dynamics. The biota was moderate impacted by chemical pollution. However, very few people live in this sub-region.

Chapter 3: Causal Chain analysis

3.1 Introduction

Based on the assessment results it was decided to perform a causal chain analysis of the high priority issues over-exploitation, chemical pollution, and habitat modification. Over-exploitation and fish/seafood habitat modification were high priority issues in West and Southeast Greenland. Chemical pollution has severe impact in East Greenland and moderate impact in North and West Greenland. Habitat modifications due to climatic change in high Arctic Greenland are a high priority problem.

Climate is a key driving force for problems of over-exploitation, chemical pollution and habitat modification and therefore, climate change is of great concern for the biota and Greenland society. However, in the GIWA context, it is considered as an environmental driving force, as it is basically related to activities outside the Greenland region

3.2 Immediate causes

Immediate causes are the direct reasons behind the environmental concerns and issues. It is important to identify the main direct causes as a scientific basis for policies and activities to achieve an improved environment

3.2.1 Over-exploitation and fish/seafood habitat modification in GIWA region 16, West Greenland

Fishing

The main immediate causes of over-fishing and the associated habitat modification are a combination of several factors: increasing fishery due to higher efficiency (new catch technology), inadequate resource management, and vulnerable resources due to climate variability. The impact of these factors is illustrated in the historically variable fishery for cod, the former most important fisheries resource.

The cod fisheries decline: The fluctuations in cod populations are well-known, as shown in Figure 11 in section 2.5. The presence of cod in Greenland waters has a periodic character. The changes in the temperature conditions in West Greenland in the 20th century generally coincide with the change of the cod fishery, indicating the existence of a relatively strong climatic effect on the cod stock. When biological fisheries research began in West Greenland in 1908-09, only small, local fjord populations of cod were present. A climatic change in the 1920's caused ocean temperatures to rise and during the following years cod became abundant along the coast of West Greenland and they dispersed northward. The general warming of the northern hemisphere around 1920 evidently lead to the establishment of a self sustaining and very abundant West Greenland cod population. From about 1930 to the late 1960s this stock produced good year classes at relatively short intervals. The drastic decline in the cod stock in the late 1960s was attributed to a combination of unfavorable cold climatic conditions and a too high fishing take in the offshore international fishery (Buch *et al.*, 1994; Horsted, 2000). No good year classes were produced by the West Greenland population after the late 1960s due to generally lower and more fluctuating water temperatures in the West Greenland area (Fig. 11). All important cod year classes in West Greenland from 1970 to the present time seem to have been of Icelandic origin (Buch *et al*., 1994). The most recent of these, the 1984 and 1985 years classes sustained relatively high catches during 1988-1990 but evidently left West Greenland thereafter (e.g., ICES, 2003). Today there are only very small local fjord populations of cod in West Greenland.

The shrimp abundance: The Greenland economy, formerly being highly dependant on a rich cod fishery, is today almost entirely dependant on northern shrimp fishery. As seen from Fig. 11 in section 2.5, the decline of cod fisheries was replaced by a corresponding increase in shrimp fisheries.

In the beginning of the 1970s new deepwater fishing technology made it possible to develop an offshore West Greenland fishery for shrimp. An inshore fishery for Greenland halibut has been taking place in Northwest Greenland fjords since the beginning of the last century. This fishery developed gradually during the 1980s and 1990s and catches are at present around 20,000 tons annually.

During the last two decades shrimp and Greenland halibut have been the commercially most important fishery resources in West Greenland. Export of shrimp to e.g. Japan, has provided a high-value economic alternative to cod, comprising 73% of Greenland’s total exports in 1995. However**,** new fisheries on snow crabs, started in late 1990s, and scallops, started in the mid 1980’s, and other mainly coastal and local fisheries on cod, salmon, redfish, wolffish, halibut, herring and others are also important for the Greenland society.

Today’s low abundance of cod and high abundance of shrimp most probably have the following main causes:

1) A general cold climate after 1970. Since 1970 the Greenland climate has been considerably colder than during the more stable warm period between 1920 and 1970. The cold conditions after 1970 have been unfavorable for growth, reproduction and survival of cod.
2) Continuing absence of the West Greenland spawning stock. The spawning stock at the banks off West Greenland is virtually absent since the collapse in the 1970s.
3) Reduced inflow of cod larvae from Icelandic spawning grounds. Since the collapse of the West Greenland spawning stock in the early 1970s, cod stocks at Greenland have been entirely dependant on recruiting year-classes from Iceland. Significant inflow of cod larvae occurred almost every year in the 1950s and early 1960s; but have since been absent except for the 1973 and 1984 year classes.
4) Reduced predation on shrimp. The low abundance of shrimp predators, mainly cod, but also other fish species has probably improved the survival success and productivity of shrimp in recent years.
5) Over-exploitation of cod. Fishing mortality on cod has been too high due to by-catch in the shrimp fishery and due to unregulated fishery directed for cod in the fjords. The resource management has been unable to adequately protect the few remaining cod spawning populations during periods of cold climate and low cod productivity.

Apparently, climatic and oceanographic changes play a very important role in the modification of the habitats and in the sustainability of the fisheries sector. This is further aggravated by overfishing in the fragile and highly variable ecosystems.

In South Greenland (15 and 16) many years of bottom trawling is believed to have impacted species compositions and community structures**.** By-catch of shrimp predators mainly cod, redfish, Greenland halibut and others in the steady growing fishery for shrimp during the last part of the 20th century has been suggested to be an important factor in the shift from cod dominated to shrimp dominated ecosystems by modifications of habitats and community structures (Bundy, 2001; Pauly *et al.*, 2001).

A general characteristic of the mainly long-lived resources exploited in Greenland waters (e.g. redfish, halibut, wolfish, Icelandic scallops, others fish and shellfish) has been a population structure with many large, old individuals when the fishery begins. But due to slow reproduction and growth rates in cold and/or deep water, the population's age structure shifts downwards as fishing intensifies, and the large older fish are removed. This trend has been observed not only with cod, but also with halibut, wolfish, scallops and other species. In the case of isolated stocks, even a short period of over-fishing leads to a drastic reduction. For example, some Greenland halibut stocks appear resident in certain fjord complexes, although reproduction occurs elsewhere (Riget and Boje, 1989). Such stocks are particularly vulnerable to over-fishing, either in the fjords or on the offshore spawning grounds.

However, in these areas the ocean climate is probably the main cause to changes in productivity and structures of the marine ecosystems. For example, for many of Greenland's fish species, the seas off Greenland limit their dispersal, for example, cod, redfish, striped catfish, halibut and herring, which have their northern limit there. Conversely, too high sea temperatures set a southern limit for the dispersal of Arctic species, such as polar cod, and Arctic ray. Therefore, relatively small variations in the temperature of the sea could result in considerable fluctuations in the dispersal and productivity of many fish species, as also observed earlier (Jensen, 1939). The trend in cod distribution by-and-large follows the average sea temperature (Horsted, 2000).

<u>Sea bird hunting</u>

The breeding populations of Brünnich's guillemot and common eider have both declined significantly in West Greenland during the 20th century. The immediate cause is ascribed to over-exploitation (Kampp *et al.*, 1994; Meltofte, 2001; Merkel *et al.*, 2002). The life strategy of both species are characterised by a slow population turn-over making the stability of the population dependant on a high adult survival. This makes the populations particularly sensitive to exploitation in periods when adult birds are exposed (mainly in spring and summer). The present annual levels of harvest as expressed by the official bag records system is about 84,000 common eiders and. 255,000 Brünnich's guillemots (maximum recorded numbers over the period 1994-2001) (Namminersornerullutik Oqartussat, 2002).

The main reasons for over-exploitation in the last century is the increased human population in West Greenland and the technical development of the hunt (more efficient weapons, faster and more far-reaching boats) combined with the low productivity of the exploited species. However, besides the hunting harvest, climatic changes, as for example the extension and duration of winter sea ice, by-catch in gillnets and disturbance (mainly hunting related) at colonies and moulting sites may also have had an impact on the populations.

Since 1930 the breeding population of Brünnich's guillemot has decreased by 80 % in West Greenland, and by 35 - 50 % in Greenland as a whole (Falk and Kamp, 2001; Kampp *et al.*, 1994). Only in the northernmost part of the breeding range (in Qaanaaq in North Greenland) the population seems stable (Falk and Kampp, 2001). The population is migratory, wintering in the open waters of Southwest Greenland and in Newfoundland waters (Kampp, 1988; Lyngs, 2003). In both areas the guillemots are exposed to hunting and significant numbers are taken. But it is difficult to assess the impact on the Greenland breeding population because the winter quarters are shared with Brünnich's guillemot populations from other breeding areas, such as Svalbard, Northeast Canada and Iceland. However, the winter hunt primarily takes juvenile and immature birds, while hunt in spring and summer near the breeding sites mainly takes local adult birds.

In the early 1970s by-catch in salmon gill-nets took huge numbers of Brünnich guillemots in Davis Strait in autumn. This by-catch declined to insignificant levels in the late 1970s, because the salmon quota was reduced and timing and location of the fishery were changed, eliminating much of the overlap with the occurrence of the Brünnnich's Guillemots (Falk and Durinck, 1991).

The part of the Brünnich guillemot breeding population wintering in Newfoundland waters is exposed to chronic oil polluting from the heavy shipping activities in these waters (Wiese and Ryan, 2003), but the impact on the population is not known.

The common eider breeding population was very large in West Greenland late in the 1800s, documented by eider down trade figures. As early as in the beginning of the 1900s concern was expressed for the status of the population due to over-exploitation (Boertmann *et al.*, in press). Locally the population has been reduced by 80% since 1960, when the population already was reduced compared to earlier in the century (Merkel and Nielsen, 2002). Exploitation is mainly hunting, and as much as 32% of the hunting bag has been taken in the spring months when the population is particularly vulnerable. The open hunting season has been reduced since 2002. The high hunting pressure is documented by the fact that a high proportion of the common eiders carry embedded lead shots in their tissues (Falk and Merkel, unpubl.). Egg collection and previously also down collection also impact the population as well. Preliminary studies indicate that by-catch in gill-nets (mainly for lumpsucker) also contribute to the mortality (Merkel, 2002b), but the impact is not known. King eiders at moulting sites also show population declines (Mosbech and Boertmann, 1999).

Marine mammals: Beluga, narwhal and walrus hunting

A number of marine mammals have been been exploited commercially in Greenland in recent times, either by whalers or by organized hunting cooperations that have sold their products on the national and international market. Subsequently, several species were and are exploited by local hunters whose hunting techniques and economic motivations resemble those of commercial whalers. This has been particularly obvious in cases where the hunting of marine mammals has been part of an overall pattern of exploitation that included fishing. Examples of this are belugas, narwhals, and walruses (Born *et al.*, 1994; Heide-Jørgensen, 2001).

The hunting of walruses in West Greenland during the 20th century is an example of how increasingly efficient hunting methods and lack of regulation may rapidly lead to over-exploitation of a group of marine mammals in which the innate capacity of increase is relatively low.

Beginning in 1911, hunting expeditions using government schooners were sent to the walrus haul-outs in West Greenland. Private motorboats soon began to participate in the hunt. The most obvious result of this intensified and uncontrolled hunting pressure was the complete disappearance after about 30 years of walruses from their haul-outs in West Greenland. They have not since returned to these haul-outs.

Since 1932, walruses have also been hunted during the spring in the West Ice off Sisimiut/Holsteinsborg to Aasiaat/Egedesminde and west of Qeqertarsuaq/Disko. The vessels used were likewise partially financed by public funds. The walrus hunt thus had the character of a commercial activity that was subsidized by the government. Great amounts of hides, tusks, and blubber were sold to the Royal Greenland Trade Company, which continued to buy these products long after it became difficult to sell them on the international market. For a number of years catches were very large; in West Greenland alone at least 12,000 walruses were landed between 1900 and 1987. The actual number of animals killed was probably much higher, because not all catches were reported and because many animals sank and were lost during hunting. Furthermore, mainly females with young were hunted in the West Ice because they were more accessible than males. The males preferred to stay in the dense pack ice further offshore. Moreover, during spring females have a relatively greater content of blubber, making them a more attractive commodity.

Even though the decrease of the walrus population in these areas was obvious relatively early, hunting regulations were not introduced until around 1950, finally affording the walruses a certain degree of protection.

The population is still far below earlier levels. Aerial surveys between 1981 and 1994 indicated that during the spring there are less than 1,000 animals in the West Ice between Sisimiut/Holsteinsborg and Qeqertarssuatsiaq/Hare Island. During this period, in which hunting continued, there have been no signs of growth in the stock.

In a “traditional” hunting community without the mechanisms of a market economy, the hunting effort is reduced as soon as the number of animals decreases, allowing the population to recover. This “feedback” regulation mechanism was put out of operation in the case of the walruses of West Greenland, because public funds were used to increase hunting effort and maintain it at a high level, even though there were signs that the population was being overexploited.

This example emphasizes the necessity of monitoring and regulating hunting efforts; this is especially true when it becomes technically and economically feasible to intensify the hunt on a population of marine mammals.

3.2.2 Chemical pollution

Long range transport and climate

The vast majority of chemical pollution in Greenland is due to long-transported contaminants from outside Greenland (AMAP, 2002; Macdonald *et al.*, 2003).

Main sources of marine pollution are the industrialised areas in Europe, Russia and USA (AMAP, 1998, 2002; Christensen *et al*., 2003). Pollutants are transported to Greenland by the atmosphere and by the marine currents, however, transportation by ice may also play a role. The prevailing patterns of wind direction, especially in winter, transport air masses from industrialised areas to the Arctic (Fig. 12). The cold Arctic climate seems to create a sink for e.g. Hg and POPs (AMAP, 1998, 2002; Macdonald *et al.*, 2003; Christensen *et al*., 2003).

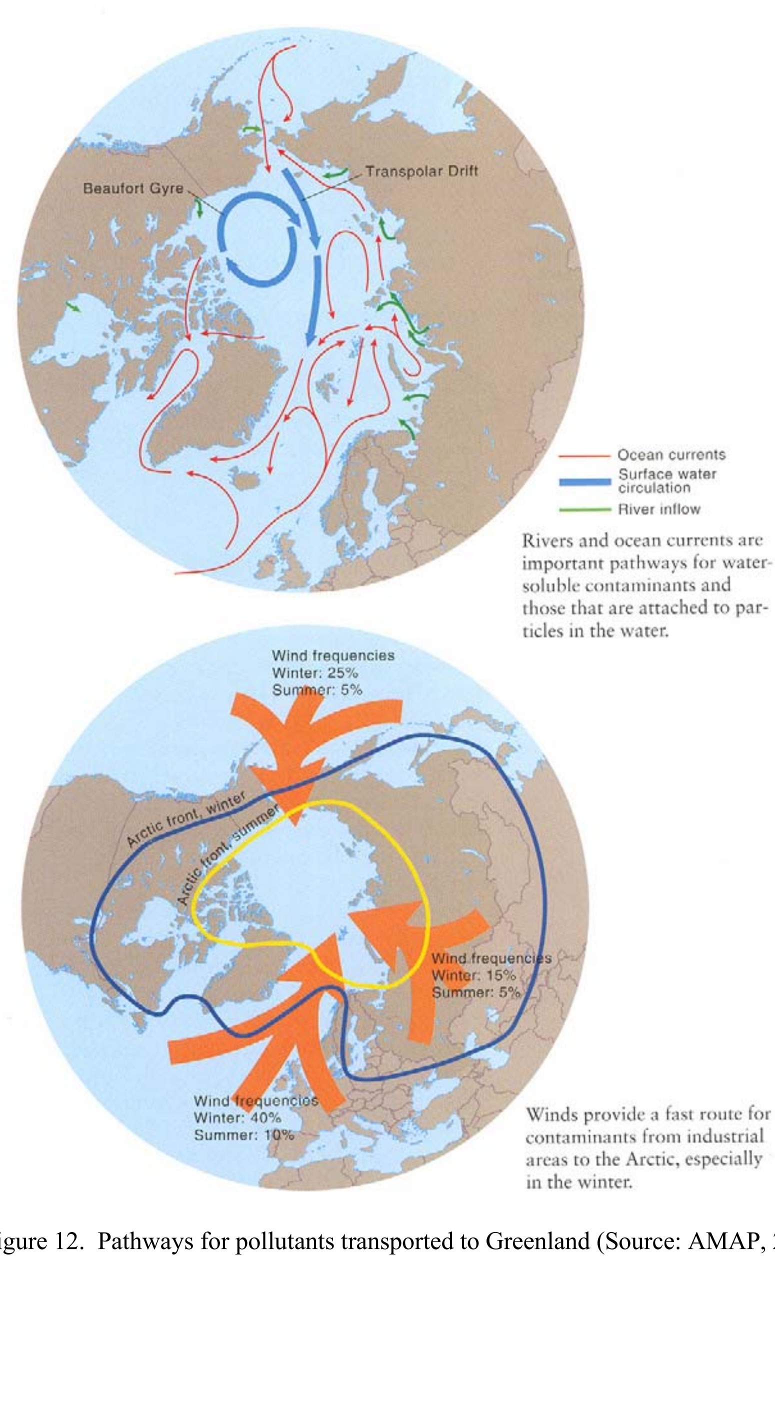


Figure 12. Pathways for pollutants transported to Greenland (Source: AMAP, 2002).

Three major mines have been in production in Greenland, and elevated heavy metal levels have been observed in fjord areas within approximately 40 km from the mine sites (Riget *et al*., 2000). However, local sources of pollutants in the marine environment around Greenland play a minor role, except for lead pollution from the use of lead shot (Johansen *et al.*, 2004).

Heavy metals:
The heavy metals assessment in AMAP focuses on mercury, lead, and cadmium. Of the metals, mercury (Hg) pollution generate the greatest concern because levels in the Arctic are already high, and are not declining despite significant emissions reductions in Europe and North America (Macdonald *et al.*, 2003).

Coal burning, waste incineration, and industrial processes around the world emit Hg to the atmosphere, where natural processes transport the metal. The Arctic is vulnerable because unique pathways appear to concentrate Hg in forms that are available to the food web. Environmental changes may have made these pathways more efficient in recent years. In the Arctic, Hg is removed from the atmosphere and deposits on snow in a form that can become bioavailable. A recently discovered process links enhanced deposition of Hg to the polar sunrise, which is unique to high latitude areas. The resulting enhanced deposition may mean that the Arctic plays a previously unrecognized role as an important sink in the global Hg cycle (AMAP, 2002). Some of the deposited Hg is released to the environment at snowmelt, becoming bioavailable at the onset of animal and plant reproduction and rapid growth. Although poorly understood, this process may be the chief mechanism for transferring atmospheric Hg to Arctic food webs.

Despite declining anthropogenic emissions, at least in the period between the 1980s and the 1990s, the Arctic ecosystem appears to be increasingly exposed to Hg (Macdonald *et al.*, 2003). It is unclear why this is so because the complete Hg pathway has not been adequately studied. The connection between atmospheric transport and deposition to Arctic surfaces (Hg depletion events) shows the Arctic to possess a unique, climate-sensitive process that may explain much of its susceptibility to Hg contamination. However, the pathway for Hg between its deposition to surfaces, especially following polar sunrise, and its concentration in apex aquatic feeders is very poorly known. AMAP recommends that studies continue on the Hg cycle in the Arctic with emphasis on the processes implicated in Hg depletion events and in the biogeochemical cycling of Hg in ice-covered environments (Macdonald *et al.*, 2003).

POPs:
Most of the total quantity of POPs found in the Arctic environment is derived from distant sources (Fig. 13). Most POPs are semi-volatile and their transport is complex. In temperate and tropical regions, they are picked up by the winds as gases. When temperatures drop, they condense onto atmospheric particles and other surfaces, reaching the ground via rain, snow, or direct deposition onto land and water. The role of atmospheric transport varies with the seasons. Generally, atmospheric long range transport to the Arctic from source areas in North America and Eurasia is much higher in winter and early spring than in summer (Macdonald *et al.*, 2003).

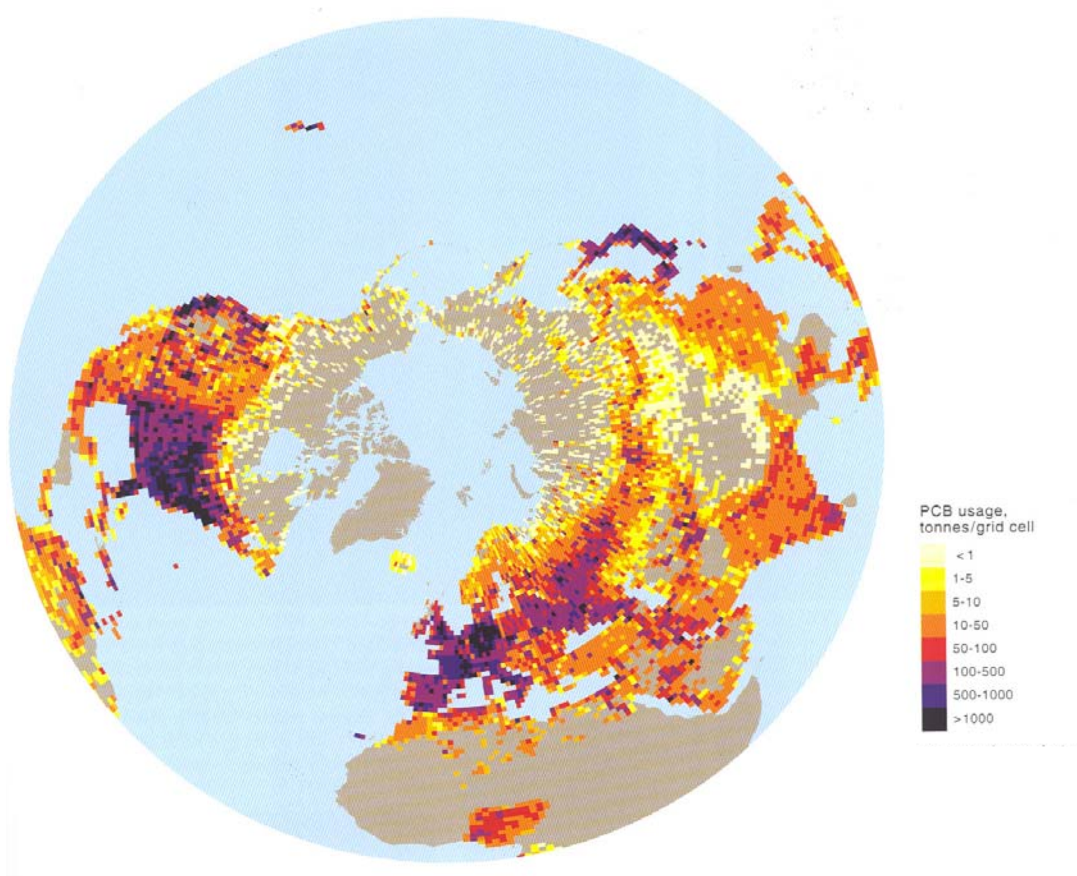


Figure 13 Estimated cumulative global usage of PCBs (1930-2000). Most of the use was in the northern temperate region (Source: AMAP, 2002).

The precise importance of ocean transport for each compound depends on the physical properties of the substance (AMAP, 2002; Macdonald *et al.*, 2003). The role of ocean currents in transport is probably more important for contaminant levels in the Arctic than was previously thought. Water soluble chemicals that are efficiently removed from the air by precipitation or air-to-sea gas exchange may reach the Arctic primarily via ocean currents.

The POPs are transported to the Arctic by regional and global physical processes, and are then subjected to biological mechanisms that lead to the high levels found in certain species. Given the length and complexity of the POP pathways into top predators of aquatic systems in the Arctic, exposure to these chemicals is particularly sensitive to global change (Macdonald *et al.*, 2003).

3.2.3. Habitat modification in GIWA region 1, Northern Greenland

Climate change
The oceanographic and sea ice conditions around Greenland are linked to climate variability and the changes in the distributions of atmospheric pressures on the northern hemisphere The last decades warming of the northern hemisphere has given reduced summer ice cover and increased open-water periods in East Greenland, however, at the same time regional lower temperatures, increased ice cover, and reduced open-water periods has been observed in West Greenland (e.g. Stern and Heide-Jørgensen, 2003). These changes have major impact on the marine ecosystems and the habitats for the Arctic animals.

In Northeast Greenland, Rysgaard *et al.* (1999) expects future increase in the annual pelagic primary production, secondary production, and hence food production for higher trophic level animals in a wide range of Arctic marine areas, as a consequence of reduction and thinning of sea ice cover due to global warming. However, the reduction in sea ice may be a benefit to some marine mammals e.g. Atlantic walruses (Born *et al*., 2003), but probably not for others e.g. polar bears (Wiig *et al*., 2003).

In West Greenland, Heide-Jørgensen and Laidre (2004) found the increased ice cover and reduction in open water refugia to be a threat to a number of sea birds and marine mammals.

The above described changes in ice cover and open water occur and impact the habitats of mainly the northern high Arctic areas of East and West Greenland. In these areas the impact of climate change are predicted to be most severe whereas in South Greenland changes in climate are expected to have less impact on habitats and ecosystems.

3.3 Root causes

The root causes are the more fundamental reasons behind the direct causes for environmental decline. Experience has shown that addressing the direct, immediate causes is not sufficient to achieve sustainable results. It is equally – and sometimes more - important to identify and consider actions related to the root causes.

Examples of some fundamental root causes are population growth, unsustainable economic development, social and cultural conditions. But lack of knowledge, inadequate governance, and lack of awareness may also be important root causes. Of special importance for the fragile ecosystems of Greenland are the basic root causes related to natural and man-induced climatic changes.

3.3.1 Over-exploitation of living resources

3.3.1.1 Climate change
Over-exploitation of fish and shellfish in Greenland is linked to global changes in climate and ecosystem functioning as illustrated in the above description of historic fluctuations in the cod populations and fisheries yields. A more detailed description is given in Buch *et al*. (2003). Changes in the thermal regime can have a considerable impact on the abundance of fishes and shellfish. Fore example Northern shrimp, snow

crab and Icelandic scallop prefer relatively cold temperatures in the range of 1-5^{o}C and especially their larvae are less vulnerable to low temperatures compared to e.g. cod. The better ability of shellfish larvae to cope with low temperature environment partly explain the positive reaction of the shrimp and snow crab stocks to the changed climatic conditions observed in West Greenland in last decades. However, the shift in the underlying marine ecosystems at Greenland may have been amplified by the declining cod stock due to a release in predation pressure on e.g. sandeel and shrimp as observed in Eastern Canada (Koeller, 2000; Lilly *et al*, 2000).

3.3.1.2 Inadequate management

During the task team meeting in Nuuk a number of root causes for over-exploitation of fishes, shellfish, sea birds and marine mammals were mentioned and discussed. They are listed according to the four dimensions of a fishery system as used by the ICES Working Group on Fishery Systems (WGFS, 2003), i.e., scientific, political, related to monitoring, control and surveillances (MCS), and user group related.

(a) Scientific documentation

An overall difficulty in fisheries and hunting assessment is to assess whether changes in the stocks are due to over-exploitation or environmental changes (changes in climate, ocean circulation, turbulence etc.). Up until now the fisheries assessment and the subsequent management methods used have generally been inadequate (e.g. Maguire, 2001).

- Inadequate data: E.g. inshore cod.
- No quantitative and analytical biological assessment and advice: E.g. offshore snow crab.
- Inadequate stock assessment: E.g., cod. The biological advice for and management of the cod fishery off Greenland is based on a combined assessment of cod in its distribution area East and West Greenland. However, the cod populations in these areas are partly separate and additionally connected to the Icelandic cod stock in a complicated way, resulting in a complex stock structure (e.g., Wieland and Hovgaard, 2002; Stein *et al*., 2002; Anon., 2003c). The complexity of the stock structure is not considered in the assessment as it is done today by ICES. There is a need for improved assessments by a better use of the available biological and hydrographic knowledge in the assessments not only for cod but also for several other exploited resources of fish, shellfish, sea birds and marine mammals.
- There is a need for improved regional stock assessments by development of coupled models of the dynamic relationship between climate, ocean circulation, and variability in key species abundance not only for cod but also for several other exploited resources of fish, shellfish, sea birds and marine mammals (e.g. Pedersen *et al*., 2002; Pedersen and Bergström, 2003; Ribergaard *et al*., 2004; Heide-Jørgensen and Laidre, 2004).

(b) Political constraints

- No regulations or inadequate regulations: This mostly applies to widely distributed fish stocks such as Greenland halibut. Often, inefficient and uncoordinated management measures lead to an uncontrolled and most probably high exploitation of the resource as is the case for Greenland halibut in East Greenland and Iceland. No formal agreement on the management of the shared

Greenland halibut stocks exists among the three coastal states, Greenland, Iceland and the Faroe Islands. The regulation schemes of those states have previously resulted in catches well in excess of TAC's advised by ICES.

- The Government subsidizes fishing and hunting gear, boats and engines.
- Foreign nations that are non-members of commissions are not restricted by regulations and measures set up by the respective coastal nations or commissions that have taken the responsibility to regulate international fisheries. Examples of this is seen in the pelagic redfish fishery in the Irminger Sea and adjacent areas, where vessels belonging to a member state of the Northeast Atlantic Fisheries Commission, re-flag under a non-member country, thereby avoiding restrictions in the fishery.
- Variable market prize differentiate fishing and hunting pressure on resources.
- Lack of transparency and accountability in the process of balancing between natural resource conservation, social and economic issues. Lack of management plans.
- Partly lack of political will to listen to biological advice.

(c) Administrative constraints

- Lack of control or inadequate control: In the wide areas of the North Atlantic schemes of control and enforcement are most often hard to accomplish, although introduction of satellite devices and a vessel monitoring system have improved control and enforcement substantially.
- Inadequate logbook reporting: E.g. inshore cod.
- No gear registration and no lost gear registration (in contrast to practice in, e.g., the Faroe Islands), resulting, e.g., in the possibility of ghost fishing by gill nets.
- Inadequate fishery administration: Fishery and hunting controls too costly or not prioritized.

(d) User-group related

- Many local communities and settlements are dependent on the harvest of marine resources because there are no other income possibilities.
- Improved fishing and hunting technology over the years.
- No flexibility in the medium- and large scale fishery e.g. seasonal shifts in target species.
- Over-capitalization (e.g., snow crab fishery).
- The need of monetary income (after change of the society to a money-based economy) increases pressure on vulnerable resources.
- Disagreement about the current resource situation between on the one hand biologists and on the other hand fisherman and hunters.

3.3.1.3 Socio-economic problems

A discussion among task team members on root causes revealed the necessity to discriminate between recreational and professional fishing and hunting. For recreational fishermen and hunters a root cause may be inadequate knowledge about the resources and inadequate understanding of the importance of observing rules and restrictions. For local professional fishermen and hunters the main root cause is probably the lack of alternatives to fishing and hunting. In families with annual income of about 50,000 Dkr per family (i.e., well below the poverty line), it is naturally difficult to reduce exploitation and thereby family budgets. Therefore, to rebuild overexploited resources, alternative income possibilities must be offered to the professional fishermen and hunters.

3.3.2 Chemical pollution in East Greenland

3.3.2.1. Lack of knowledge
In spite of recent progress, in particular due to the findings of the AMAP programme, there are still considerable uncertainties about the sources, the transport mechanisms and the impacts of the arctic food chains of chemical pollutants. In particular, documentation to pinpoint key international causes is needed to form a better scientific basis for reduction of the impacts

3.3.2.2. Lack of international governance
The major sources for the chemical contamination of the waters and the ecosystems around Greenland can be found in the pollutant releases in Europe, Asia and North America. The only possibility of reducing these sources is a continued focused and significant international effort to control these emissions, and to enforce existing agreements.

3.3.2. 3 Socio-economic conditions
The combination of environmental conditions and biomagnification in the marine food webs result in accumulation of certain persistent contaminants in traditional food of the Greenland people. For many reasons, traditional food still plays an important role in the diet of the population, in particular in the settlements

The consumption of marine mammals, fish and sea birds is high but the young and the population in towns eat considerably less than the elderly and the population in the villages. Seal is the most often consumed traditional food item followed by fish. On average, 20% of the Greenlanders eat seal 4 times a week or more often while 17% eat fish similarly often. Traditional food is valued higher than imported food; the highest preference is given to mattak (whale skin), dried cod, guillemot, and blackberries. Almost all value traditional food as important for health and less than one percent (in 1993-94) restricted their consumption of marine mammals or fish because of fear of contaminants (Bjerregaard, 2003).

3.3.3. Habitat modification

3.3.3.1 Climate change
The main root cause for habitat modifications in the Northern waters is variability in climate, and hence, global climate change. In addition to the natural variations, anthropogenic climate change is one of the major emerging environmental problems. Although the climate system is complex and large uncertainties exist in the understanding and prediction of climate change, the question is no longer if we will experience climate change, but how large anthropogenic and natural changes will be, how fast they will appear and their regional variations (Jørgensen *et al*., 2001).

Analyses with global climate models show the following general trend for the climate in Greenland in 2100 in relation to 1990 (Anon., 2003a):

- in South Greenland a rise in mean annual temperature of just over 2ºC, slightly more in winter and slightly closer to 2ºC in summer, and in North Greenland, a rise in temperature of 6-10ºC in winter but only small rises in summer;
- a general increase of 10-50% in precipitation, but little or no increase in Southeast Greenland. In winter, however, a considerably bigger increase in North Greenland, locally up to more than 100%.

Such changes will cause significant impacts on the oceanographic conditions and on the stability of the ice cover. It is questionable if the present arctic ecosystems will be able to accommodate these changes.

3.3.3.2 Lack of knowledge
There is a considerable lack of both data and understanding of how the arctic ecosystems will react to possible drastic changes in the climate and ice-cover.

3.4 Conclusion
Over-exploitation of the marine resources, in particular in West Greenland, GIWA region 16, partly due to climate change, inadequate knowledge of the living resource dynamics, and management, and partly due to the ability or inability of the municipality to react and adapt to changes, is a severe problem and one of the large challenges for Greenland now and in the future (Fig. 14).

Chemical pollution from outside Greenland is a threat to the biota at higher trophic levels, human health and the culture of the Arctic people, in particular in East Greenland, GIWA region 15 (Fig. 15).

And finally, habitat and community modifications due to climate change, but also over-exploitation are threats to many unique Arctic animals, (e.g., polar bears, walrus) in particular in the North, GIWA region 1

Some of the root causes for the key environmental concerns of Greenland's marine resources are to be found and solved within Greenland. However, climate change greatly influences the natural resources and is a very important factor for Greenland's ability to manage natural resources and socio-economics relationships in the society.

Hence, the main international problems for the waters around Greenland, the biota and the society are chemical pollution and climate change. Both these problems are caused by the industrialized world and they are global international problems to be solved in international cooperation.

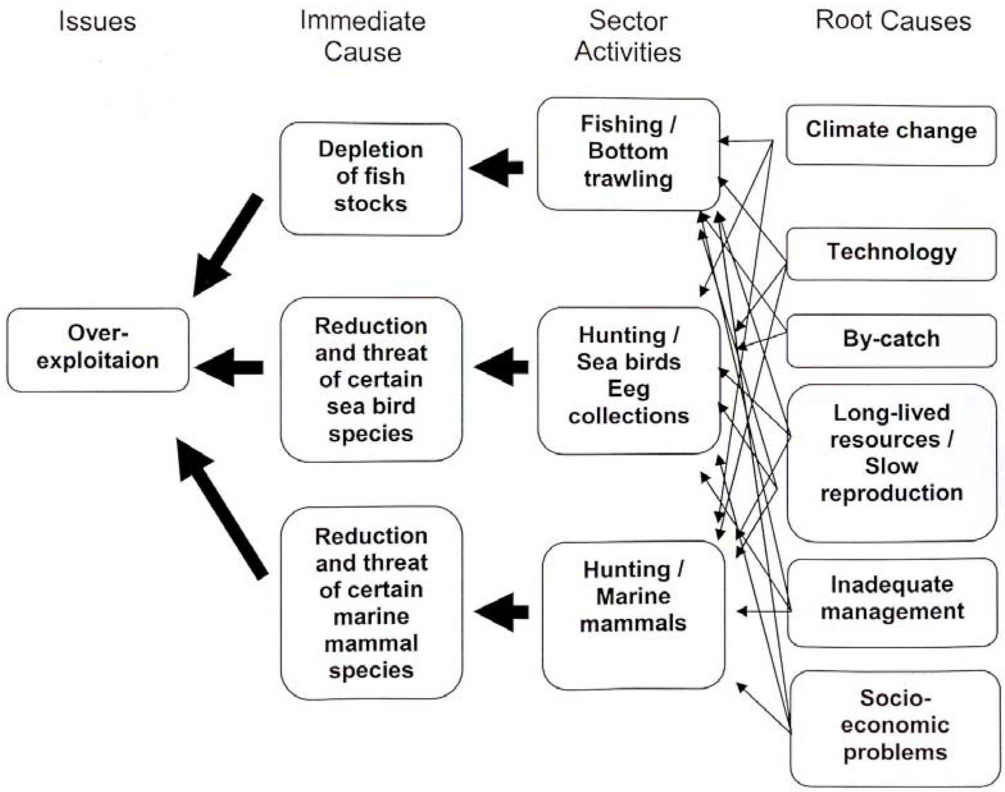


Figure 14. Causal chain analyses over-exploitation.

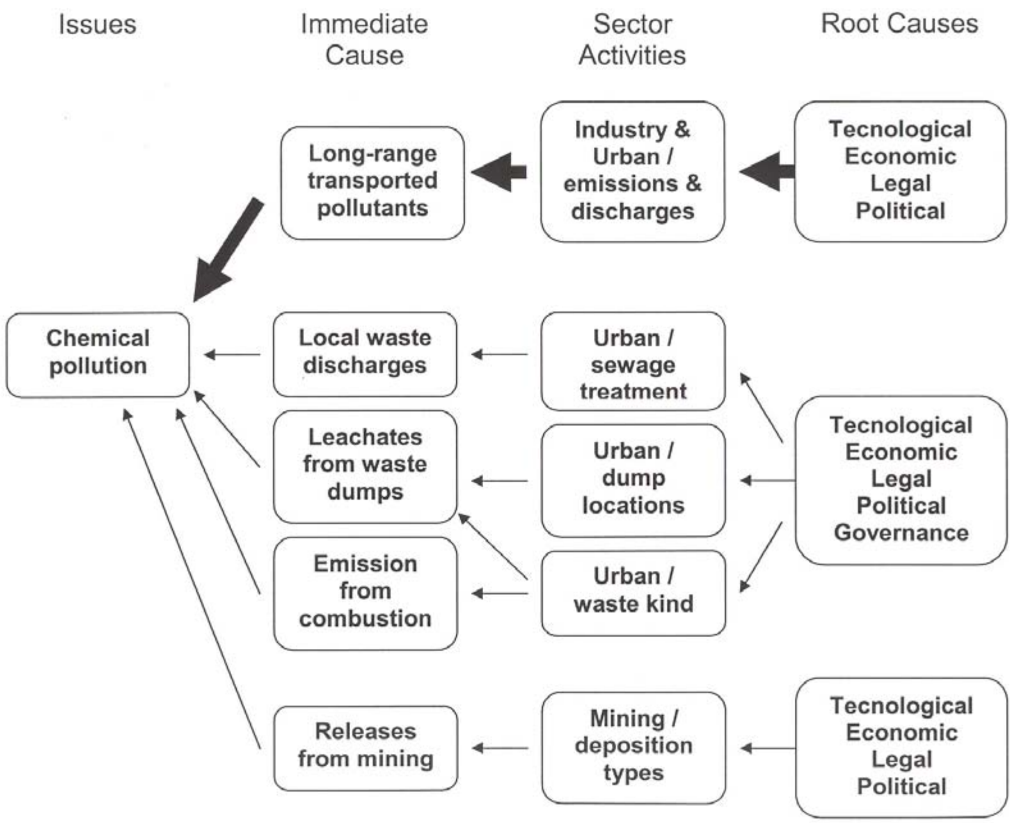


Figure 15. Causal chain analyses chemical pollution.

Chapter 4: Policy Option analysis

4.1 Key issues and causes

The assessments and the causal chain analysis identified the following key issues:

- West Greenland (GIWA region 16) suffers from overexploitation of the marine resources, due to climatic changes, inadequate knowledge about the resource dynamics and productivity of the ecosystems, inappropriate management frameworks, and a lack of population awareness and ability on how to best adapt to the changes.
- East Greenland (GIWA region 15) - and to a certain degree West Greenland - suffers from the impacts of chemical pollution, transported by the air and ocean currents from Europe, Asia and North America, and building up in the food webs of the arctic marine ecosystems. There is a need to further improve the understanding of the transport processes and to improve the international cooperation to reduce emission of hazardous chemicals.
- North Greenland (GIWA region 1) is presently fairly undisturbed, but it is expected that global climatic changes related to emission of green house gases may cause significant threats to the arctic ecosystems, in particular the unique arctic mammals (polar bears, walrus, etc.). There is a need to further understand these impacts, and to use this information in the international climate negotiations.

4.2 Options for policy intervention

The politicians and the administration in Greenland are fully aware of the issues and the threats they pose to the socio-economic development. Accordingly, a large number of policy initiatives – both nationally and internationally have been initiated. The following sections will highlight some of particular importance to the issues identified above, and also point out some additional options for intervention.

4.2.1 Addressing Over-exploitation of marine resources in West Greenland

In 1987 the “Brundtland Report” (World Commission on Sustainable Development 1987), also known as *Our Common Future*, alerted the world to the urgency of making progress toward economic development that could be sustained without depleting natural resources or harming the environment. The report provided a key statement on sustainable development, defining it as: *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*.

There is great awareness in Greenland about the urgency of sustainable development in the society (see www.nanoq.gl /sustainability). Quoting Jonathan Motzfeldt, former Premier, Greenland Home Rule Government (Greenland Institute for Natural Resources 2002: Foreword):

> *“The marine ecosystem is the life-blood of Greenland. There is a tight connection culturally, socially, and economically, and mankind is, more significantly than anywhere else, integrated into the ecosystem.*

> *The wide-spread realms of the Arctic marine region have, through the centuries, drawn fishermen and hunters from far and wide. But human influence, and rapid climatic change, have induced marked shifts in the ecosystem, and the focal points of exploitation have changed through time.*
>
> *Rapid climatic shifts and a low level of complexity make the Greenland marine ecosystem uniquely suitable for the study of the effects of climate change. At the same time, the situation of the ecosystem within a single economic zone gives good possibilities for studying the interactions between it and society. Together, these factors make this a unique study area, of international interest for investigating the effects and interactions between mankind, climate, and ecosystem.*

4.2.1.1 Improved Knowledge

In their discussion of the concept of sustainability in fisheries, Steele and Hoagland (2003) argue that one of the main difficulties in fisheries management is the "ratchet" effect (Ludwig *et al*., 1993). When the abundance of a stock increases, the fishing capacity goes up. But when later the stock decreases – often by natural causes - , the effort stays the same, usually with disastrous consequences for the stock and the economy. This general sequence occurs on top of a trend for "improved" gear technology. The critical scientific problem is to distinguish between these two causes: natural environmental variability and changes in effort, fishing boats and gear. According to Steele and Hoagland (2003) the time scale of natural changes in the sea - a few decades - is comparable to the economic scales of human adaptation; specifically the "lifetime" of a fishing vessel. It is this resonance in time scales that makes the attribution of cause to the quasi-cycles in stock abundance more than a purely scientific problem. There is a need to understand the natural physical and ecological causes of these "cycles" in marine ecosystems and subsequently devise sufficiently long term management to ameliorate rather than amplify the economic consequences (Steele and Hoagland, 2003).

Much of this and related discussion was taken up by the Food and Agriculture Organisation (FAO) of the United Nations in discussions related to the Convention relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (UN, 1994) and the Code of Conduct for Responsible Fishing (FAO, 2001), and recently resulted in Technical Guidelines for an Ecosystem Approach to Fisheries Management (FAO, 2003). These guidelines have been adopted to reflect the merging of two different but related and – it is hoped – converging paradigms. The first is that of ecosystem management, which aims to meet its goal of conserving the structure, diversity and functioning of ecosystems through management actions that focus on the biophysical components of ecosystems (e.g. introduction of protected areas). The second is that of fisheries management, which aims to meet the goals of satisfying social and human needs for food and economic benefits through management actions that focus on the fishing activity and the target resource. Up until recently, these two paradigms have tended to diverge into two different perspectives, but the concept of sustainable development (World Commission on Environmental and Development, 1987) requires them to converge towards a more holistic approach that balances both human well-being and ecological well-being. Ecosystem Approach to Fisheries (EAF) is, in effect, a way to implement sustainable development in a fisheries context (FAO, 2003).

The Greenland Institute of Natural Resources is the Greenland Home Rule Government's centre for research on living natural resources. It advises the government on sustainable use of resources, including conservation of the environment and biological diversity. The Institute's vision is to understand the interrelationship between ecosystem, climate and human impact.

The Greenland Institute for Natural Resources wishes to initiate a long-term research programme towards its vision, in order to meet the increasing interest in ecosystem-based advice for management (Jarre, 2002). The focus will be the marine ecosystem off West Greenland, both economically and socially most important to Greenland's society.

The goal of the "Ecosystem West Greenland" (ECOGREEN) research programme is to establish a scientific basis for a long-term ecosystem-based management of natural resources in West Greenland waters"

Through the research programme ' ECOGREEN', Greenland expects to attract international expertise within the natural- and social-science research communities, which in fellowship with Greenlandic institutions can create a scientific basis for holistic management of a marine ecosystem.

The results from ECOGREEN could well become the basis for developments in more complex systems, and its perspective therefore extends far beyond Greenland.

4.2.1.2 Improved management

Key questions concerning management of human use of natural resources and the need for socio-economic research in the West Greenland ecosystem were discussed during a workshop at Greenland Institute of Natural Resources in 2001. The following is quoted from the workshop report (Jarre, 2002, p77-78):

> *The need for communication on management issues*
>
> *"In the end it is the person with the finger on the trigger or the person setting the net, who decides whether their action is complying with, or violating the law." said Paviaraq Heilman, then member of the Home Rule Government, during the seminar on Greenland's living resources conducted by the Greenland Institute of Natural Resources in 1998. In a country where it is practically impossible to control compliance with hunting and fishing regulations, it is the people's knowledge, understanding and acceptance of management measures that leads to compliance with regulations.*
>
> *In connection with strategies for sustainable exploitation, experts and practitioners have been analysing for a number of years how the needed change of behaviour can be achieved. Consensus is growing that active participation in the management process is one of the necessary conditions.*

<u>Solution co-management?</u>
In International Union for Conservation of Nature (IUCN), World Wildlife Fund (WWF) and the Arctic Council, co-management is propagated as the best solution to management issues. In the report "Arctic Flora and Fauna. Status and conservation" (CAFF (ed.) 2001, Edita, Helsinki. 272 p.- free online version: www.caff.is) it is concluded that "One of the most notable recent innovations is the involvement of hunters and fishers in wildlife management. In theory, hunters and fishers who help develop the regulations will better understand the rationale for them and be more willing to abide by them. In practice this approach has enjoyed success in North America, where support for co-management has grown widely, although difficulties remain."

Acknowledging that co-management in Greenland is only in its infancy, the Directorate for Environment and Nature of the Home Rule Government published a "programme proposal for local engagement in management of natural resources in Greenland" (Greenland Home Rule, www.nanoq.gl). Quoting from the proposal:

"The programme's aim of seeking a broader basis for management principles - and letting the process of reaching agreement on the basic principles become a part of the programme, thereby creating local awareness of the consequences of a general natural resource policy - is new in Greenland".

"One of the conditions for solving these problems is that a real alternative is created to enable many of those who are today dependent on the very direct utilisation of our live resources to earn a living. Moreover, subsidies to the fishing industry and the hunting trade should be arranged so that they do not contribute to maintaining the existing pattern".

"In order to counter any negative development there is a distinct need for two concrete initiatives: 1. an information campaign and an open and honest dialogue about the problems in this country, and 2. the formulation of an overall policy for the solution of the problems, resulting in an actual strategy and action plan"

According to Greenland Home Rule (www.nanoq.gl), the purpose of the campaign is to ensure better dialogue between interest groups and to disseminate factual information about the status of living resources, the objective being to create a common understanding of what is needed to conserve the natural environment for future generations.

At the same time the campaign is hoped to enable Greenland to live up to its obligations in terms of information to the public about environmental issues and protection of the natural environment as required in two international conventions:

- The Biodiversity Convention, which Greenland has signed and according to which signatory countries are obliged to initiate public education and awareness programmes; and
- The Aarhus Convention on access to information about environmental matters, which Greenland stated it would endeavour to observe when Denmark ratified it. According to the Aarhus Convention citizens are not only entitled to

> information about environmental matters: public authorities have an obligation of pro-active dissemination of information. With the new nature conservation act which is expected to be adopted within the next twelve months. Greenland lives up to the spirit of the Aarhus Convention in a number of areas: the establishment of an environmental complaints board and the potential establishment of a nature protection council.

According to Sejersen (2003) the Greenland society should continue discussions and reevaluations of the terms optimal and sustainable use of the natural resources under the changing environment.

In relation to development of tourism in Greenland, Kaae (2003) suggests priority to projects integrating tourism, natural science, and sustainable use of nature. For example project cooperation between research institutions and the tourist business, and projects which better integrate and make use of local Greenlandic expertise.

4.2.2. Addressing Chemical pollution in West and East Greenland

Environmental chemical contaminants are a global problem. Their presence and role in the Arctic reflects the physical, biological, and social characteristics of the region, as well as the way the Arctic interacts with the rest of the world.

The pollution stemming from the industrialized world is caused by a complex of causes and the solution is to stop/reduce the chemical pollution which leads to problems for the biota in Greenland. The latter needs international actions such as AMAP and the OSPAR Commission (see AMAP, 2002; OSPAR Commission, 2000). However, pollution from mining and hunting is mainly a "local Greenland" problem, as the use of lead shot contaminates bird's meat, which subsequently is a significant lead source to bird eaters (Johansen *et al.*, 2004). This problem may be solved by replacing lead with non-toxic alternatives.

4.2.2.1 Improved knowledge

Current concern about Arctic contaminants began with discoveries of high levels of persistent organic pollutants (POPs) in some indigenous inhabitants of the Arctic. Subsequent research confirmed that Arctic animals have elevated levels, posing a threat not only to the people who eat them but also to the animals themselves, and their ecosystems.

In 1991, the eight Arctic countries – Canada, Denmark, Finland, Iceland, Norway, Sweden, Russia, and the United States – initiated the Arctic Environmental Protection Strategy.

Under this framework, the countries pledged to work together on issues of common concern. Recognizing the importance of the environment to the indigenous communities of the Arctic, the countries at that time included three indigenous organizations in their cooperative programs. In 1996, the eight Arctic countries created the Arctic Council, incorporating the Arctic Environmental Protection Strategy and expanding it to include sustainable development issues. They have also included three more indigenous organizations for a total of six permanent participants.

One of the programs created under the Arctic Environmental Protection Strategy and continued under the Arctic Council is the Arctic Monitoring and Assessment Programme. AMAP was designed to address environmental contaminants and related topics, such as climate change and ozone depletion, including their impacts on human health (AMAP, 2002). Its specific task in Phase I of its existence was to prepare a comprehensive scientific assessment on these matters.

The conclusions and recommendations from the first scientific assessment led to substantial progress in addressing the problem of contaminants. They raised the profile of environmental contamination in the Arctic as a public policy issue, and helped in the preparation of dietary guidelines in several countries.

4.2.2.2 Improved international cooperation

At the time AMAP began its work, the United Nations Economic Commission for Europe (UN ECE) Convention on Long-range Transboundary Air Pollution was already considering whether it should take action on POPs and heavy metals. The data compiled by AMAP over the next several years established a strong case for restricting or eliminating several POPs.

Several important steps have already been taken to address the threats POPs pose to the Arctic environment, such as the Stockholm Convention and the UN ECE POPs Protocol. The AMAP (2002) assessment shows the continued need to bring Arctic concerns about POPs to the attention of these international policy fora to ensure continued emphasis on Arctic needs.

Conventions regulate some POPs

At a national level, the use and emissions of many POPs have been restricted since the 1970s. In 1998, the United Nations Economic Commission for Europe (UN ECE) negotiated a regional protocol on POPs under the Convention on Long-range Transboundary Air Pollution, the Aarhus POPs Protocol, which covers Europe, all states of the former Soviet Union, and North America. All AMAP countries except Russia are signatories to this convention. As of August 1, 2002, the following AMAP countries had ratified the POPs Protocol: Canada, Denmark, Norway, and Sweden. They were able to do so in part because they had learned much from AMAP concerning transboundary contaminants in the Arctic. Indeed, the preamble to the Stockholm Convention explicitly recognizes the risks POPs pose to Arctic ecosystems and indigenous health and well-being.

The regional UN ECE agreement paved the way for global negotiations on banning POPs under the auspices of the United Nations Environment Programme. The Stockholm Convention on Persistent Organic Pollutants was opened for signature in May 2001. All AMAP countries have signed the Stockholm Convention. As of July, 2002, Canada, Iceland, Norway, and Sweden had ratified it.

Both agreements identify a number of specific POPs to be banned or whose use or emissions are to be restricted. They include industrial chemicals and by-products, such as PCBs, dioxins, furans, and hexachlorobenzene. Also included are a number of organochlorine pesticides: aldrin, chlordane, dieldrin, DDT, endrin, heptachlor, mirex, and toxaphene. Together, these are often called the ‘dirty dozen’. Some POPs, most notably the pesticide hexachlorocyclohexane (HCH), are covered in the UN ECE Protocol but not the Stockholm Convention. For several of the listed substances, some limited use is allowed, for example DDT for fighting malaria.

The conventions also define criteria for including new chemicals based on their persistence, bioaccumulation, potential for long-range transport, and adverse effects. The Arctic is well suited as an indicator region for long-range transport. Monitoring data that provide information about the fate of chemicals in the Arctic will therefore be critical in identifying new POPs to be considered under the agreements.

In addition to national regulations concerning emissions and use of heavy metals, some significant steps have recently been taken internationally to address the heavy metals. The United Nations Economic Commission for Europe (UN ECE) Convention on Long-Range Transboundary Air Pollution adopted a Protocol on Heavy Metals in 1998. The protocol targets mercury, lead, and cadmium. Countries that are party to the protocol will have to reduce total annual emissions to below the levels they emitted in 1990.

As of June 15th, 2002, there were 36 signatories to the protocol, including all the Arctic countries except Russia. Of these, 10 had ratified it, including Canada, Denmark, Finland, Norway, Sweden, and the United States. For the protocol to enter into force, sixteen countries must ratify it. At its meeting in 2000, the Arctic Council called on the United Nations Environment Programme (UNEP) to initiate a global assessment of mercury that could form the basis for appropriate international action. This request was based on the findings of AMAP’s first assessment.

In 2001, the UNEP Governing Council agreed to undertake such a study. At the same time, UNEP agreed to tackle the issue of lead in gasoline. The study on mercury will summarize available information on the health and environmental impacts of mercury, and compile information about prevention and control technologies and practices and their associated costs and effectiveness. In addition, the UNEP Governing Council requested, for consideration at its next session in February 2003, an outline of options to address any significant global adverse impacts of mercury. These options may include reducing and or eliminating the use, emissions, discharges, and losses of mercury and its compounds; improving international cooperation; and enhancing risk communication.

The Arctic Council also decided to take cooperative actions to reduce pollution of the Arctic. In 1998, the Regional Programme of Action to Prevent Pollution of the Arctic Marine Environment from Land-Based Activities was adopted. As a direct follow-up of the AMAP scientific assessment, the Arctic Council Action Plan to Eliminate Pollution of the Arctic was created to address sources identified by AMAP. This plan was approved in 2000 and several projects have begun.

In addition to its recommendations on contaminants, the AMAP assessment recommended further work on climate change and ultraviolet radiation. In 2000, the Arctic Council approved the Arctic Climate Impact Assessment, overseen by AMAP, its sister working group on Conservation of Arctic Flora and Fauna (CAFF), and the International Arctic Science Committee. According to AMAP (2002), this impact assessment will deliver a report to the Arctic Council in 2004.

4.2.3 Addressing Habitat modification in North Greenland

As described above

4.2.3.1 Addressing global climate change

Habitat modification due to climate change is a global problem, and climate change is dealt with by UN Intergovernmental Panel on Climate Change (IPCC) (e.g., Jørgensen *et al*., 2001; Anon., 2003a).

The Kingdom of Denmark comprises Denmark, Greenland and the Faroe Islands. The UN Framework Convention on Climate Changes has been ratified on behalf of all three parts of the Kingdom (Anon., 2003a).

The ultimate objective of international climate cooperation is described in Article 2 of the UN Framework Convention on Climate Change, namely to achieve a "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system".

In September 2001, the UN Intergovernmental Panel on Climate Change (IPCC) presented its Third Assessment Report. The report shows that there is now stronger evidence for a human influence on the global climate than previously assumed, and that most of the observed warming at the Earth's surface over the last 50 years is likely to have been due to human activities.

The climate changed during the twentieth century, and larger changes are expected in the twenty-first century. No one knows the exact scope of future climate change. However, today no one can doubt the risk that climate change will affect humans and the environment in both the rich and the poor parts of the world. Taking climate change seriously has become a prerequisite for achieving sustainable development.

The Danish government takes global climate change seriously, within the framework of the Kyoto Protocol, under the auspices of the EU, Denmark is committed to reducing its emissions of greenhouse gases by 21% in 2008-12 compared to the level in 1990, taking into account the unusually high import of electricity in 1990 (Anon, 2003a). This is one of the hardest reduction targets in the world.

Since Denmark issued its First (1994) and Second (1997) National Communication under the UN Climate Convention, the Kyoto Protocol has been adopted, and the Conference of the Parties has taken the decisions necessary on realisation of the Protocol. Denmark ratified the Kyoto Protocol together with the other EU countries on 31 May 2002. The Danish government hopes that the Protocol will enter into force in 2003, policies and measures, including national action plans are described in Anon. (2003a).

As part of the national action plans for Greenland the GIWA-Greenland task team experts recommended that Greenland participate actively in the International Polar Year 2007. The year 2007-2008 will mark the 125th anniversary of the First International Polar Year (1882-1883), the 75th anniversary of the Second Polar Year (1932-1933), and the 50th anniversary of the International Geophysical Year (1957-1958). It will obviously be a good idea for Greenland to actively participate in the planning of the International Polar Year 2007 (http://ipy.gsfc.nasa.gov/). The IPY-2007 will be a good opportunity for Greenland to inform the world of the severe changes for Arctic life caused by the predicted global warming.

4.3 Conclusions

Many of the root causes for over-exploitation of Greenland's marine resources are to be solved within Greenland. However, climate change and chemical pollution from outside Greenland influence and have severe impact on the dynamics of natural resources and human health in Greenland. Both climate change and chemical pollution are caused by the industrialized world and they are global international problems to be solved in international cooperation. It is important for Greenland to inform the UN and the world about the impact of climate change and chemical pollution and to take active part in solving the root causes to the problems. Through its memberships and active participation in international organizations e.g. Arctic Council, AMAP, ICES, NAFO, JCCM, NAMMCO, IWC, etc., Greenland is very aware of the threats to the habitats, biota, and human health of over-exploitation, climate change and chemical pollution, and want to actively participate in the international discussions to address the external impacts on the marine ecosystems of Greenland.

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ANNEX 1

List of GIWA - Greenland task team experts – meeting participants and contributors:

The "Stage 1: Scaling and Scoping" meeting held 15. August 2003 at the National Environmental Research Institute (NERI) (www.dmu.dk):

Frank Riget (Main issues: Chem. Pollution/Env. Assessment/exploitation), Senior Research Scientist, NERI, E-mail: ffr@dmu.dk
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The "Stage 1: Scaling and Scoping" meeting held 3. September 2003 at the Greenland Institute of Natural Resources (GINR) (www.natur.gl):

Astrid Jarre (Main issues: Env. Assessment/exploitation/economy), Senior Research Scientist, GINR, E-mail: astrid@natur.gl
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* Not present at the scaling and scoping meetings

ANNEX 3a

Report Sheet I. Description of indicators substantiating environmental impacts of the selected priority Major Concern and Issue(s) under present conditions.

Sub-region No. 1/15/16

Sub-region Name: Arctic/East-/West Greenland

Selected Priority Major Concern: IV. Unsustainable Exploitation of Living Resources

Priority GIWA Issue: Issue 14. Over-exploitation

Score received in the Scoping: 0/3/3

Environmental Impact Indicator and its unit	Format: Map, report, data table, etc.	Extent or Area covered	Duration and Frequency	Reliability	Availability	Source of information or contact to obtain data or information	Brief explanation or justification how the indicator supports your conclusion made in the Scaling and Scoping
Reduced catches and abundance indices of fish stocks	Data, reports	Sub-regions: 15 and 16	Catch statistics 1950-; German survey 1982-; Greenland survey 1988-;	High	Free	National data / NAFO / ICES	Reduction in catches and abundance indices. Smaller sizes of fish in trawlsurveys (e.g. Pedersen and Kanneworff, 1995; Rätz, 1999).
Decreasing seabird populations	Data, reports	Sub-regions: 16	Observations since 1920	High	Free	National data / NERI /GINR	Reductions in breeding and non-breeding populations.
Reduced abundance indices of walrus and beluga populations	Data, reports	Sub-regions: 16	Catch statistics 1900-; Observations during several aerial surveys since 1981-	High	Free	National data/ NERI	Reduction in abundance indices (NAMMCO and JCCM).

Report Sheet II. Description of proxy indicators substantiating socioeconomic impacts of the selected priority Major Concern under current conditions

Sub-region No. 1/15/16 Sub-region Name: Arctic/East-/West Greenland

Selected Priority Major Concern IV. Unsustainable Exploitation of Living Resources

Socioeconomic Impact	Socioeconomic proxy indicator and its unit	Format: Map, report, data table, etc.	Extent or area covered	Duration or Frequency	Reliability	Availability	Source of information or contact to obtain data or information	Brief explanation or justification how the proxy indicator supports your conclusion made in the Scaling and Scoping
Economic Impacts Score: 0/2/2	Unknown						No data exists	It was discussed by the task team and judged that there probably was a moderate economic impact in East and West Greenland
Health Impacts Score: 0/0/0	Unknown						No data exists	
Other Social and Community Impacts Score: 0/0/2	Unknown						No data exists	It was discussed by the task team and judged that there probably was a moderate sociocial and community impact in West Greenland

Worksheet CCA I. Description of indicators or quantitative information substantiating links between a priority Issue and Immediate Causes in the Causal Chain

Sub-region No.: 1/15/16 Sub-region Name: Arctic/East-/West Greenland Selected priority Major Concern: IV. Unsustainable Exploitation

Over-exploitation

link

Priority GIWA Issue

Immediate Cause	Indicator or supporting information	Format: map, report, data table, etc.	Extent or Area covered	Duration	Reliability	Availability	Sources of data or contact to obtain data and information	Brief explanation or justification how the indicator support your link between Issue and Immediate Cause
Fishing (New and improved technology)	Catch statistics	Data reports	Sub-regions: 15 and 16	1900-	Moderate-High	Free	National data / NAFO / ICES	Reduced catch
	Abundance Indices	Data reports	Sub-regions: 15 and 16	German survey: 1982- Greenland surveys:1988-	High	Free	National data	Reduced abundance
Hunting (increased hunting pressure due to population increase and improved technology)	Seabird surveys (breeding and non-breeding)	Data reports Scientific papers, Models	Sub-region 16	Since 1900-	High	Free	National data/NERI/GINR/	Reduced abundance indices
	Catch statistics	Data reports	Subregion 16	1995-2002	Moderate	Free	Greenland Homerule	High harvest of selected species
Climate change	Hydrography Sea temperature	Data, reports	Sub-regions: 15 and 16	1950-	High	Free	National data / ICES	Weak associations between cod abundance and sea temperature
	Trends in sea ice	Data reports	Subregion 16	1953-2001	High	Free	GINR	Increase in extend of winter ice

If the Immediate Cause(s) cannot be quantified, please provide qualitative information or justification to support your links between the priority Issue and Immediate Causes:

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Worksheet CCA II. Description of indicators or quantitative information substantiating links between Immediate Cause and Sector Activities in the Causal Chain

Sub-region No.: 1/15/16 Sub-region Name: Arctic/East-/West Greenland Selected priority Major Concern: Unsustainable Exploitation

Over-exploitation ← Technological developments and climate induced variability in stock production / stock distribution ← link

Priority GIWA Issue — Immediate Cause

Sector	*Indicator or supporting information*	Format: map, report, data table, etc.	Extent or Area covered	Duration	Reliability	Availability	Sources of information or contact to obtain data and information	Brief explanation or justification how the indicator support your link between Immediate Cause and Sector Activities
International fishing	Reduced size of common fish stocks	Data, reports	Sub-regions: 15 and 16	1950-	Inter-mediate	Free	National / ICES	Model simulations made by ICES (ACFM) stock assessment 2003
	Reduced size/weight of individual fish	Data, reports	Sub-regions: 15 and 16	1982-	High	Free	National	Model simulations made by ICES (ACFM) stock assessment
Local fishing	Reduced landings of fish	Data, reports	Sub-region 16	1992-	High	Free	National	National survey data
Local Hunting	Decreasing breeding seabird populations	Reports	Sub region 16	1900	High	Free	GINR; NERI	Adult mortality too high caused by spring and summer harvest
	Breeding seabirds extremely shy	Anecdotal evidence	Subregion 16	1975	High	Free	GINR, NERI	In areas without hunt same species less shy
	High proportion of seabirds carrying shotgun pellets	Data	Subregion 16	1995-2002	High	Free (perhaps not yet)	GINR and NERI	Indicator of a high hunting pressure.
Global climate	Change in NAO indices	Data, reports	North Atlantic	1900-	High	Free	National	Associations with fish stock abundances and distributions
	Extend and duration of sea ice	Data, reports	Sub region 16	1953-2001	High	Free	GINR	Reduced availability of feeding and breathing areas for seabirds and marine mammals

If Sector Activities cannot be quantified, please provide qualitative information or justification to support your links between the Immediate Cause and the Sector Activities:

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Worksheet CCA III. Description of indicators or quantitative information substantiating links between Sector Activities and Root Causes in the Causal Chain

Sub-region No.: 1/15/16 Sub-region Name: Arctic/East-/West Greenland Selected priority Major Concern: Unsustainable Exploitation

Over-exploitation ← Technological developments and climate induced variability in stock production - stock distribution ← Market economy / economical development ← Socio-cultural development ← link

Priority GIWA Issue

Immediate Cause

Priority GIWA Issue Immediate Cause 1st Intermediate Cause **Driving Forces**	**Indicator or supporting information**	**Format: map, report, data table, etc.**	**Extent or Area covered**	**Duration**	**Reliability**	**Availability**	**Sources of information or contact to obtain data and information**	**Brief explanation or justification how the indicator support your link between Sector Activities and Root Causes**
Global socio-economical development and climate change	Increased number of motorboats and modern fishing and hunting technology	Data, reports					Statistics Greenland	
Inadequate management of seabird populations	Illegal hunting, hunting in sensitive periods, missing refuges	reports	Sub region 16	1950-	High	Free	GINR, NERI	Too many adult birds are shot during mating and breeding time

If the Root Cause cannot be quantified, please provide qualitative information or justification to support your links between the Sector Activities and the Root Cause

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ANNEX 3b

Report Sheet I. Description of indicators substantiating environmental impacts of the selected priority Major Concern and Issue(s) under present conditions.

Sub-region No. 1/15/16

Sub-region Name: Arctic/East-/West Greenland

Selected Priority Major Concern: II. Pollution

Priority GIWA Issue: Issue 6. Chemical

Score received in the Scoping: 2/3/2

Environmental Impact Indicator and its unit	Format: Map, report, data table, etc.	Extent or Area covered	Duration and Frequency	Reliability	Availability	Source of information or contact to obtain data or information	Brief explanation or justification how the indicator supports your conclusion made in the Scaling and Scoping
Levels of contamination in biota	Data, reports	Sub-regions: 15 and 16	1994-2003; 5 year intensiv	High	Free	National data: AMAP/EPA	High levels of heavy metal and POP's, exceeding int. threshold levels
Levels of contamination in human	Data, reports	Sub-regions: 15 and 16	1994-2003; 5 year intensiv	High	Free	National data: AMAP/EPA	High levels of heavy metal and POP's, exceeding int. threshold levels
Levels of metal in biota/mining	Data, reports	Maamoriliik/ Ivittuut/ Mestersvig	1980's-2003; 3-5 year interval	High	Free	National data/ NERI	High conc. Of levels of Pb, Zn in marine environment following deposition of tailings from mining
Levels of contaminats in marine env. /dump sites	Data, reports	Thule/ Sisimiut	184, 2002, ?	High	Free	National data/ NERI	Elevated conc. Due to leaching from dumps (metals, POPs)

Report Sheet II. Description of proxy indicators substantiating socioeconomic impacts of the selected priority Major Concern under current conditions

Sub-region No. 1/15/16 Sub-region Name: Arctic/East-/West Greenland

Selected Priority Major Concern II. Pollution, Issue 6. Chemical

Socioeconomic Impact	Socioeconomic proxy indicator and its unit	Format: Map, report, data table, etc.	Extent or area covered	Duration or Frequency	Reliability	Availability	Source of information or contact to obtain data or information	Brief explanation or justification how the proxy indicator supports your conclusion made in the Scaling and Scoping
Economic Impacts Score: 0/0/1	Cost of water cleaning							
Health Impacts Score: 0/3/3	Human health indicators	Data, repots	Selected sites	From the 1990s	High	Free	AMAP, Human Health	Hormone/ enzyme indicators of human health
Other Social and Community Impacts Score: 0/3/2								

Worksheet CCA I. Description of indicators or quantitative information substantiating links between a priority Issue and Immediate Causes in the Causal Chain

Sub-region No.: 1/15/16 Sub-region Name: Arctic/East-/West Greenland Selected priority Major Concern: Pollution, Issue 6. Chemical

Chemical pollution

link

Priority GIWA Issue

Immediate Cause	*Indicator or supporting information*	Format: map, report, data table, etc.	Extent or Area covered	Duration	Reliability	Availability	Sources of data or contact to obtain data and information	Brief explanation or justification how the indicator support your link between Issue and Immediate Cause
Long transport	Atmospheric deposition	Data reports	Nuuk/ Station Nord	2001-	High	Free	NERI/AMAP	Arctic sunrise deposition of Hg
	Levels of contaminants in biota	Data reports	Sub-regions: 15/16	1994-	High	Free	NERI/AMAP	Levels in biota reflect long-transport
Local discharge	No. of dumps	Map	Sub-regions: 15/16	Survey 2001	High	Free	Greenland Home Rule	Describes potential leaching from dumps
	No. of incinerators	Data table	Sub-regions: 15/16	?	High	Free	Greenland Home Rule	Reflects treatment of water deposition types
Mining	Levels in biota	Reports	Local mines	1980-	High	Free	NERI	Leaching from mines is reflected in biota

If the Immediate Cause(s) cannot be quantified, please provide qualitative information or justification to support your links between the priority Issue and Immediate Causes:

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Worksheet CCA II. Description of indicators or quantitative information substantiating links between Immediate Cause and Sector Activities in the Causal Chain

Sub-region No.: 1/15/16 Sub-region Name: Arctic/East-/West Greenland Selected priority Major Concern: Pollution, Issue 6. Chemical

Chemical pollution ← Long-range transport / local ↰ link

Priority GIWA Issue — Immediate Cause

Sector	*Indicator or supporting information*	Format: map, report, data table, etc.	Extent or Area covered	Duration	Reliability	Availability	Sources of information or contact to obtain data and information	Brief explanation or justification how the indicator support your link between Immediate Cause and Sector Activities
Longe-range Industry outside Greenland	Emission/transport to Greenland	Model output	Sub-regions: 1/15/16	2000-	Inter-mediate	Free	NERI / AMAP	Models for the transport of pollutants to the Arctic
Local urbanization need for treatment	Municipal discharge							
	% of treated waste water							
Local mining industry (Need for reduced leaching)	Conc. Of metals in indicators in biota	Reports	Mines in Sub-regions: 15/16	1980-	High	Free	NERI	Conc. Describe trends in leaching
	No. of active mines	Report	Mines in Sub-regions: 15/16	1980-	High	Free	NERI	Shows scale of potential problem

If Sector Activities cannot be quantified, please provide qualitative information or justification to support your links between the Immediate Cause and the Sector Activities:

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Worksheet CCA III. Description of indicators or quantitative information substantiating links between Sector Activities and Root Causes in the Causal ChainSub-region No.: 1/15/16 Sub-region Name: Arctic/East-/West Greenland Selected priority Major Concern: Pollution, Issue 6. Chemical

Pollution ⇐ Longe-range transport ⇐ Industry ⇐ Emission from industry / urban cities ↰ link

Priority GIWA Issue Immediate Cause 1st Intermediate Cause **Driving Forces**	***Indicator or supporting information***	**Format: map, report, data table, etc.**	**Extent or Area covered**	**Duration**	**Reliability**	**Availability**	**Sources of information or contact to obtain data and information**	**Brief explanation or justification how the indicator support your link between Sector Activities and Root Causes**
Use of chemicals in industrialized world	Total emission of Hg, POPs	Reports					AMAP	The total emission indicate the trend in transport to the Arctic

If the Root Cause cannot be quantified, please provide qualitative information or justification to support your links between the Sector Activities and the Root Cause
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